PROYECTO FIN DE CARRERA

SIMULACIÓN DEL COMPORTAMIENTO TÉRMICO DE UN EDIFICIO CON UNA HERRAMIENTA DINÁMICA: EL CASO DE LAS NORMATIVAS ITALIANA Y ESPAÑOLA.

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INTRODUCTION

According to the European Union, more than the 40% of the primary energy is consumed by the residential sector, and this trend keeps on growing. Saving energy consumed by the buildings represents a way to fulfil targets established in Kyoto Protocol. Because of this, the European Union has established a new directive on Building's Energy Performance (EPBD), which has as primary target to improve Buildings' energy performance in EU members.

Probably, one of major steps forward taken by the (EPBD), is that it sets a mandatory energy certification of buildings. Due to this, is necessary to set a common methodology, at national or regional level, of calculation of the energy performance in buildings. In this situation, one of the tools that can be used to analyze energy performance of buildings, is the software available in the market nowadays. With the objective of analyzing this software, a research called "Rapporto sull'analisi di codici di calcolo per la valutazione energetica degli edifici" was written in Perugia (September 2008).

The first objective of this study, is to analyze and compare the results obtained in this report with a simulation carried out with the software TRNSYS. In a first approach, we will suppose that TRNSYS provides the most accurate results, since it is a transient simulation program. After the comparison, TRNSYS pros and cons will be analyzed. This will be done in the first phase of the project.

In this first phase, we will describe TRNSYS mathematical procedure and the step-by-step procedure carried out to specify all the characteristics of the building studied in this project on TRNSYS.

The second objective of the research, is to analyze Italian and Spanish national regulations related to the transposition of the EPBD. Here, a comparison between three Italian and three Spanish cities with similar degree-days, will be carried out with the software TRNSYS under the regulations existing for both countries. The results obtained in this second phase of the project will be used to examine the regulations undertaken in both countries, concluding which one is the most restrictive.

1.- CONTRIBUTION OF THE BUILDING SECTOR TO THE GREENHOUSE EFFECT.

In this section, some of the principles of the Greenhouse Effect are explained focusing on the contribution of the building sector to this effect. As we will see, the building sector has a great influence in the overall greenhouse gases emissions. This, might represent the highest potential sector for decreasing greenhouse gases emissions. So, this section will focus on the importance in reducing the emissions related to the building sector. This, may represent an economical and technological feasible way to reach the targets established by Kyoto Protocol.

1.1 Principles of greenhouse effect:

The greenhouse effect, is a naturally occurring process that changes earth's energy balance by blocking part of the longwave radiation which is reflected by earth's surface. This process causes the heating of earth's atmosphere, making its average temperature of 14ºC instead -18ºC, which is the blackbody temperature of earth, if calculations are performed using the Stefan-Boltzmann equation. So, greenhouse effect is an essential process which enables life on earth. The problem comes when industries gases emissions, cause a rise in the proportion of these gases existing in the atmosphere, which may cause a global temperature rise.

There are certain gasses which are responsible of this effect, such as carbon dioxide, water vapour, methane, and other human-made refrigerants. Each of these gases has a different equivalent greenhouse power according with an equivalence that has been established with carbon dioxide, which is the anthropogenic greenhouse effect gas that exists in a major proportion in the earth's atmosphere.

1.2 The earth's energy balance:

Sun's energy passes through the atmosphere since the sun is transparent to the visible light. A 26% of this energy is reflected by the clouds back to the sky. Other 19% is absorbed by clouds and particles in the atmosphere. Consequently, the remaining 55% of the energy coming from the sun reaches earth's surface. A 4% of this energy is reflected back to the space by earth's surface so, an average a 51% is absorbed on earth's surface.

Energy reaching earth's surface causes it's heating. When this happens, earth's surface becomes a radiator of energy in longwave band, called infrared radiation. All this energy is usually directed to the space. However, only a small proportion escapes from earth’s atmosphere. Greenhouse gases absorb the majority of this radiation emitting in longwave band, as well. Approximately, a 90% of this radiation is emitted back to the Earth’s surface were it once again, is absorbed by the surface. This radiation heats the ground once again, repeating this cycle until no more longwave is available for absorption.

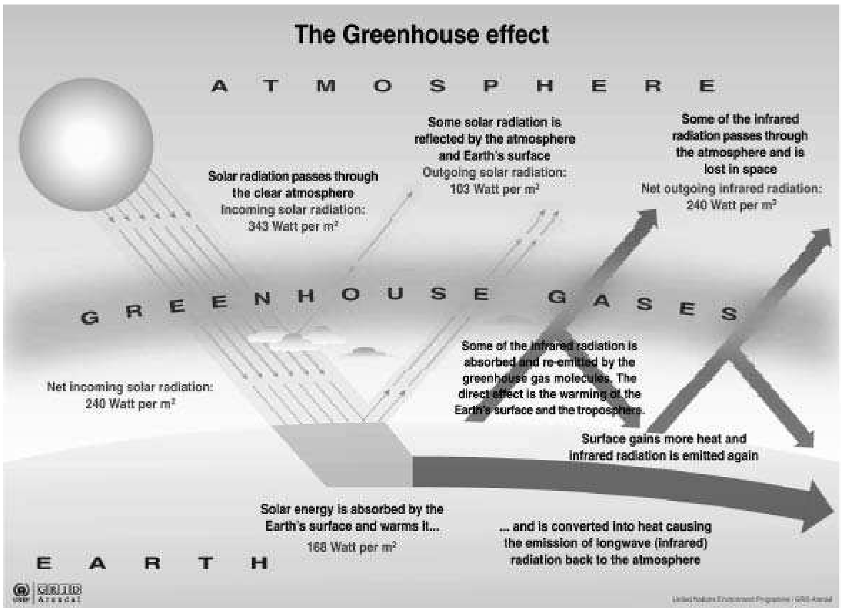


Fig.1.1: Earth’s energy balance. Source Okanagan University College, University of Oxford, EPA, IPCC, Philippe Rekacewicz

The amount of Energy trapped in Earth’s atmosphere, depends on the concentration of greenhouse effect gases existing in it. Greenhouse effect is a natural-occurring process, which has enabled life on planet but, by increasing the concentration of these gases in the atmosphere, this process can be altered, changing consequently, earth’s energy balance, causing the rising of Earth’s mean temperature.

This concentration has been altered since the beginning of the Industrial Revolution, when the first mass production of carbon dioxide was emitted to the atmosphere. From this moment till nowadays, this trend has been increased.

As a result of a higher concentration of greenhouse gases existing in the atmosphere, Earth’s mean temperature is predicted to be increased. However, there is a possible negative feedback effect caused by the progressive warming of earth, i.e. Earth’s warming will make the oceans warmer, this may cause an increase of water evaporation process causing a major proportion of clouds in atmosphere. These extra clouds, will reflect a greater proportion of energy coming from the sun reducing the amount of energy absorbed by the atmosphere and Earth's surface. With less energy, greenhouse effect may be balanced back again.

1.3 Gases involved in the greenhouse effect.

The absorption of infra-red rays, which is the cause of global warming, primarily occurs in molecules comprised of three or more atoms; all the greenhouse gases fulfil this criterion.

Another characteristic that should be taken into account is the spam of these greenhouse gases. For instance, even if a particular substance has a significant global warming potential, and is emitted in considerable quantities, the problem will not be serious as long as the substance decomposes quickly and in a manner whereby the greenhouse effect ceases.

Greenhouse gases are those which have the characteristic of absorbing and emitting energy in a longwave band or infrared range. There are, existing in the atmosphere, many different kinds of these gases. However, these are the most important.

In decreasing order, the most abundant greenhouse gases existing in the atmosphere are:

- Water vapor
- Carbon dioxide
- Methane
- Nitrous dioxide
- Ozone
- CFC´s

Their influence and proportion in the greenhouse effect is:

Greenhouse gas	Contribution to the Greenhouse effect
Water vapour	36–70%
Carbon dioxide	9–26%
Methane	4–9%
Ozone	3–7%

Chart 1.1. Influence and proportion of the greenhouse gases.

The proportion and the contribution to the greenhouse effect fluctuates locally between the range expressed above. The contribution to the greenhouse effect by a certain gas depends both on the characteristics of the gas, (the global warming potential), and its abundance. For example, if we have the same cuantity of a refrigerant (CFC 11, which its global warming potential is of 4500) and of carbon dioxide (which its global warming potential is of 1), in this situation, the refrigerant has a major contribution to the greenhouse effect. However, carbon dioxide is present in a higher concentration, so its contribution is greater.

Aside of the human-produced synthetic refrigerants, most of greenhouse gases came from natural suorces and human activities. Human activities have changed the concentration of carbon dioxide, methane and synthetic refrigerants, mainly.

Here, in chart 1.2 , there is detailed information about the main anthropogenic and natural greenhouse gases and the human influence in their concentrations through the industrial era, some information about theirs sources is detailed as well.

Greenhouse effect Gas	Concentration in 1750	Concentration in 2003	Percent Change since 1750	Natural and Anthropogenic Sources
Carbon Dioxide	280 ppm	376 ppm	34%	Organic decay; Forest fires; Volcanoes; Burning fossil fuels; Deforestation; Land-use change
Methane	0.71 ppm	1.79 ppm	152%	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous Oxide	270 ppb	319 ppb	18%	Forests; Grasslands; Oceans; Soils; Soil cultivation; Fertilizers; Biomass burning; Burning of fossil fuels
Chlorofluorocarbons (CFCs)	0	880 ppt	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents
Ozone	Unknown	Varies with latitude and altitude in the atmosphere	Global levels have generally decreased in the stratosphere and increased near the Earth's surface	Created naturally by the action of sunlight on molecular oxygen and artificially through photochemical smog production

Chart.1.2. Greenhouse effect gases.

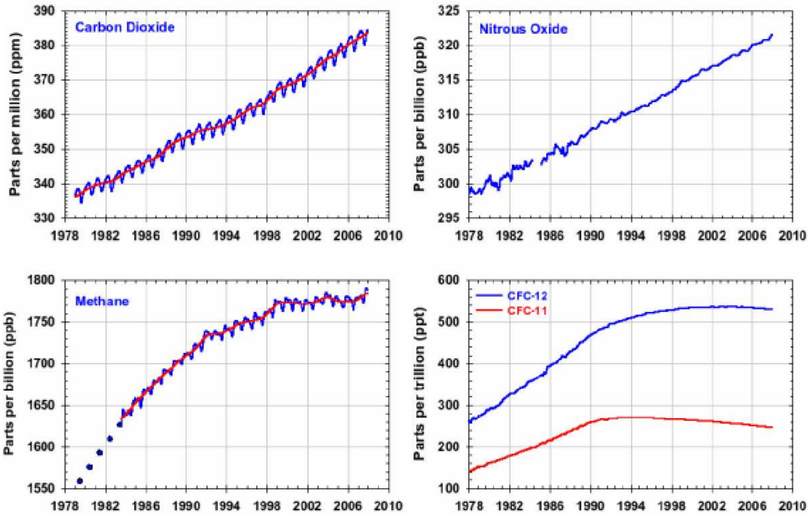


Fig.1.2. This figure shows the evolution and fluctiation of concentration in the atmosphere of Carbon Dioxide, Nitrous Oxide, Methane and Refrigerants CFC 11 and CFC 12.

As we see in the figure 1.2, Carbon dioxide and Nitrous dioxide emissions have a linear trend during time. This means that the emissions rates have not been changed during the last 30 years. On the other hand, we see how refigerants CFC-11 and CFC-12 concentrations have decreased in the last years due to the Montreal Protocol.

1.4 The Kyoto Protocol:

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. It sets binding targets for 37 industrialized countries and European Community to reduce greenhouse gas emissions, (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride), and two groups of gases, **(**hydro-fluorocarbons and perfluorocarbons**),** produced by industrialized nations. These amounts to an average of five per cent against 1990 levels over the five-year period from 2008 to 2012.

Kyoto Protocol has been ratified by 183 parties, which it was initially adopted for use on 11 December 1997. Kyoto includes "flexible mechanisms" such as Emissions Trading, the Clean Development Mechanism and Joint Implementation to allow developed economies which have ratified the protocol, fulfil their GHG emission limitations by purchasing GHG emission reductions credits from other undeveloped countries or developed countries with excess allowances.

Europe:

In Europe, targets estabilished by Kyoto protocol have became a main prioriy. In Europe, approximately from a 40 to a 50 per cent of the global emissions of GHG are related to the building sector. In order to reduce significantly GHG emissions of EU member states and fulfil Kyoto targets in a efficient manner, the European parlament has estabilished the European Directive 2002/91/CE in Energy Performance of Buildings, (Known as the EPBD), with the main target of increasing building's energy performance in EU members.

In this research, we will discuss the different applications of this directive depending on the EU Member in wich it has been adopted. We will see the differences between the regulations of two EU Members like Italy and Spain by simulating different situations according to their own national regulations.

1.5 Contribution of building´s to the greenhouse effect.

Contibution of worldwide building's to the greenhouse effect:

Greenhouse gas emissions from buildings worldwide are set to increase over the next two decades, mainly, due to construction booms in Asia, the Middle East and Latin America.

The estimated 8.8 billon tonnes of greenhouse gases thrown to the atmosphere related to the building sector, could be doubled by 2030 reaching 15.6 billion tonnes under the high-growing development scenario existing nowadays, according to the Intergovernmental Panel on Climate Change (IPCC).

A 90 per cent of the energy that a building consumes during its useful life, is consumed for heating, cooling and lighting. Is here, were efforts on energy saving must be focused in order to provide an economic and effective way to reduce emissions and saving energy. The rest (a 10 per cent) is consumed during the construction, material manufacturing and demolition process.

Measures like an improved insulation and ventilation, increased use of natural lighting, and improving performance of lighting, heating and cooling systems -which are the targets of the new directives on buildings performance- can become a way of saving energy and reducing GHG worldwide emissions.

For instance, through renovations, the Swedish standard of an office building in Stockholm can be reduced from $\frac{145kWh}{m^2 of\_useful\_area}$ to $\frac{115kWh}{m^2}$. With the new construction techniques and materials, this standard could be reduced to $\frac{80kWh}{m^2}$. This represents energy efficiency increases of approximately 20 percent in existing buildings and up to 50 per cent in the new ones. This represents a great share in global GHG emissions which could be saved.

Europe:

In order to fulfill Kyoto Protocol and keep greenhouse gases concentrations between a reasonable range, carbon dioxide equivalent concentrations should be no greater than 400 ppm. Nowadays this concentrations are around 380 ppm as explainded above, this enviromental limitation leads the needing to reduce to almost zero the fossil fuel emissions by 2050. This represents a great technological, economical and political challenge.

The main sectors in the EU for the energy consumption and, consequently, greenhouse gases are transport and buildings. The sector of transport is always having advances and technological updates, reducing GHG emissions and contamination, and increasing fuel performances. However, the building sector, because of both long life use and great energy demand is a critical sector which uses a great share of EU´s energy production.

The residential sector and the tertiary sector, which its major part are buildings, takes more than the 40%, as we remarked before, of EU´s energy comsumption. This makes this sector the greatest contributor to the greenhouse effect in the E.U. Taking all these facts into account, bulding´s sector represents the largest potential sector for cutting GHG emissions, which are known to be responsable of global warming. This means that buildings, in contrast to popular belief, contribute more than transport sector (31 percent) and industry (28 percent) to the greenhouse gases emissions.

In Europe, the building sector could reduce the emissions of GHG by between 20 and 25 per cent in the next 10-20 years if appropriate measures are taken. This represents a great share in the contribution to the worldwide emission of GHG. European regulations like EU Directive 93/76/CEE, the EU Directive 2002/91/CE and the EU Green Paper, give a view of the priority that the EU has for reducing the energy consumption in the building sector in order to reduce its energy dependency as well as fulfilling international agreements like Kyoto protocol.

Knowing all these facts, is important to determinate how the application of European Directive of energy performance in buildings is applied in each EU member, and how this law, can affect to the energy requirements of buildings and their contribution to the GHG emissions. This, among others, will be a target of this project.

2. REGULATIONS ANALYZED

In this section, the Italian and Spanish national regulations on Energy Performance of Buildings will be exposed under the European directive framework.

2.1 The European directive on the energy performance of buildings (umbrella document):

2.2.1. Introduction.

Most European countries have established their own building regulations in place for too much time. Most of them were inspired by the first oil crisis of the decade 1970, only concerning the reduction of winter heating needs. Requirements may vary from country to country or from region to region, but mainly, they consist of varying insulation of structures according to the severity of the local climate. Some of them include passive solar gains contributions and requirements concerning air-thickness insulation, quality of thermal bridges on facades, and details affecting building energy requirements during winter (Visier, 2004)[5].

The focus on reducing heating bills in the 1970's was such that some errors were even made, namely an excessive effort to improve air- tightness of the building envelopes to reduce infiltration levels without an accompanying care to provide sufficient mechanical ventilation means. Resulting into serious indoor air quality problems that are well known and documented: (Sick- Building Syndrome, or Sick Buildings).

Some countries have updated their regulations, others, maybe too many, have not for quite long, as energy prices have been reasonably low during the last decade of the twentieth century and early twenty first. A significant change took place in 2004, as a reaction to the "new oil crisis".

All these situations plus environmental goals, such as the Kyoto Protocol, and a certain number of recent important electricity summer blackouts caused by the air- conditioning devices, have given an important impetus for changing this situation.

The European Union adopted in December 2002 the Directive on the Energy Performance of Buildings (EPBD) that, among other issues, requires EU Member States to review their building energy regulations by 4 January 2006, using a common methodology defined, in general terms, by the EPBD itself.

The details of the EPBD or Umbrella Document will be explained in the next section.

2.1.2 The EPBD.

The EPBD establishes five main requirements for EU Member States:

- Harmonisation of building calculation methodologies;
- Establishment of minimum requirements for new buildings and for major interventions.
- Mandatory building’s energy certification
- Regular inspections of heating and cooling systems;
- Accreditation of experts carrying out the work of certification and inspections of boilers and air-conditioners.

Around the year 2000, there is a wide variation of requirements between the different Member States in terms of their National Building Regulations and construction practices. Although each country can set its particular targets according to the Umbrella Document, the European Commission wishes a certain degree of convergence on the transposition of this document.

The Directive was published in 4 January 2003 and the Member States must implement it in a period of three years. So, after the 4th of January 2006, EPBD must be set and working in all the EU Members. The requirements relating to certification and inspection of boilers and air conditioners can be delayed three more years because a lot of trained and certified experts and inspectors are needed to fulfil this requirement.

2.1.2.1 Minimum requirements for new buildings (Buildings of new construction) and buildings under major interventions.

On the article 3, the EPBD requires that “*Member States shall apply a* ***methodology****, at national or regional level,* ***of calculation of the energy performance of buildings*** *on the basis of a general framework…*”

This methodology (an annex to the directive) includes:

- Building’s thermal characteristics (Building’s thermal envelope and partitions). Here, it may also be included characteristics referring to the air tightness.
- Heating installation and hot water supply, including their insulation characteristics.
- Air- conditioning installation.
- Mechanical ventilation.
- Built - in lighting installation (mainly the non- residential sector).
- Position and orientation of buildings, including outdoor climate.
- Passive solar systems and solar protection.
- Natural ventilation.
- Indoor climatic conditions, including the designed indoor climate.

The positive influence of the following aspects will, where relevant in this calculation, be taken into account:

- Active solar systems and other heating and electricity systems based on renewable energy sources.
- Electricity produced by CHP (Combined Heat and Power).
- District or block heating and cooling systems.
- Natural lighting.

The energy performance of a building must be expressed in a clear manner and may include a CO_2 emission indicator.

The methodology is explained in the figure below (figure 2-1.1), and is based in series of new CEN standards.

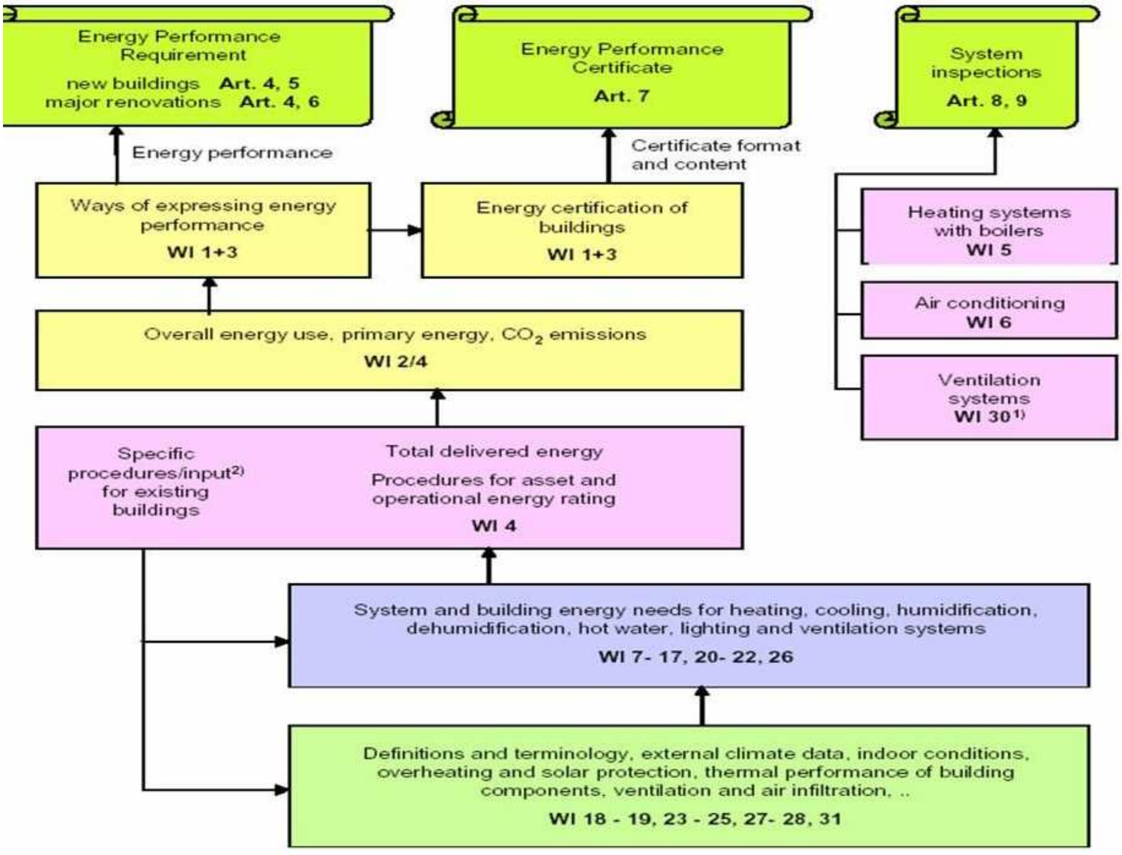


Fig.2-1.1 The new CEN standards for supporting the implementation of the EPBD.

The new revised version of EN ISO 13790 includes cooling and lighting calculations. In its new version, the standard allows three alternative methods for calculating energy needs for heating and cooling:

- A default monthly method.
- A seasonal method.
- A yearly hourly **simulation** procedure, with single zone or multizone options, based on simplified models for the building, allowing for consideration of more complex use patterns, e.g., free-cooling, ventilation, casual occupancy, etc, which is the one performed in this project.

EU members can adopt any of these options.

In article 4, is required that: "*Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings are set, based on the methodology referred to in Article 3.*".

The EPBD distinguishes the following categories of buildings:

- Single family houses of different kinds.
- Apartment building blocks.
- Offices.
- Buildings with education purposes.
- Hospitals.
- Hotels and restaurants
- Sports facilities
- Wholesale and retail trade services buildings
- Other types of energy- consuming buildings.

Some exceptions are allowed:

- Buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic heritage, where compliance with the requirements would unacceptably alter their character or appearance.
- Temporary buildings with a planned time of use of 2 years or less, industrial sites, workshops and non- residential agricultural buildings with low energy demand which are in use by a sector covered by a national sectorial agreement on energy performance.
- Buildings used as places of worship and for religious activities.
- Residential buildings which are intended to be used less than 4 months of the year.
- Stand- alone buildings with a total useful floor area of less than 50 m^2.

The EPBD also establishes that the requirements must be reviewed at regular intervals no longer than 5 years, updated with latest technical progress in the building sector.

For the new buildings, the Directive requires that: "*Member States shall take the necessary measures to ensure that new buildings meet the minimum energy performance requirements*". For **new buildings** with an useful surface greater than 1000 m^2, EU Members must ensure that these following devices are installed.

- Decentralised energy supply systems based on renewable energy.
- CHP (Combined Heat and Power).
- District or block heating or cooling, if available.
- Heat pumps, under certain conditions.

For **existing buildings** with a floor useful area greater than 1000 m^2 undergoing a major intervention, the EPBD specifies: *"their energy performance must be upgraded in order to meet minimum requirements in so far as this is technically, functionally and economically feasible."* This means that upgradings will be carried out, provided that the are economically possible, not imposing any measure that might be cost-effective.

Finally, EPBD sets clearly the definition of a major intervention. There are two possible definitions:

- There is an intervention in more than the 25% of building's thermal envelope.
- The cost of the intervention is greater than the 25% of the cost of the construction of the building.

2.1.2.2 Energy certification of Buildings:

Article 7 of the EPBD sets that every new building must be enclosed by an Energy Certificate, and for every existing building a certificate must be provided the moment it is sold or rented. For large public buildings with an useful surface greater than 1000 m^2 this certificate should be updated periodically and displayed on a well visible location at the building's entrance.

This certificates must be written by accredited, recognized, independent bodies.

The validity of the certificate will not exceed 10 years, but EU Members can define lower periods of validity.

For apartments or building blocks with housing purposes, there are two different ways to certificate the building:

- If the building has a common heating system, through a common certification for the whole building.
- By assessing an apartment which is representative of the whole building.

The EPBD also specifies that: *"the energy performance certificate for buildings shall include reference values such as current legal standards and benchmarks in order to make it possible for consumers to compare and assess the energy performance of the building"* , and *"the certificate shall be accompanied by recommendations for the cost-effective improvement of the energy performance."*

2.1.2.3. Inspection of Boilers and Air-Conditioners.

Articles 8 and 9 of the EPBD establish that EU Members must ensure regular inspections for boilers and air-conditioners above a certain power.

This inspections may vary depending on the power of the device and the energy source used:

- Boilers of an effective rated output of more than 100 kW shall be inspected at least every 2 years. For gas boilers, this period may be extended to 4 years.
- Gas boilers below 100 kW are not required to have regular inspections.
- Heating systems with more than 15 kW, older than 15 years. must be inspected once. This inspection will include an assessment of the boiler energy efficiency and a comparison of boiler sizing with building's energy requirements.

Article 9 of the EPBD, requires inspections of air- conditioning systems over 12 kW. This inspection must include an assessment of the air- conditioning efficiency and a comparison of A/C sizing with the building's cooling requirements.

2.2 Italian regulation

2.2.1. Introduction:

The Italian regulation used during the performance of this study was Decree no. 192/05 related to the transposition of the Directive 2002/91/EC [1]. Italian regulation establishes limits for:

- Primary energy requirements for heating expressed in kWh/m^{2}year. These limits depend on the form factor which is the ratio area/volume[1].

- Heat transfer coefficients of the opaque and transparent structures of the building envelope. This limits are set for years 2006, 2008 and 2010 which become increasingly restrictive. In this project, 2008 regulation will be studied[1].

Decree 192/05 must be applied to all new buildings. The only cases that can be excluded are:

- Historical buildings.
- Industrial and agricultural buildings which may need heating requirements only for production process purposes.
- Insulated buildings with a useful surface smaller than 50 m^2.

In the rest of cases: Depending on intervention performed on the building, there are 3 different possible applications:

- Application to the whole building.
- Application to an existing building but only to the enlarged zones of it.
- Application limited only to a few parts of an existing buildings which will be changed or altered.

Italian law divides the country into six different climatic zones, from A to F, organized according in an increasing order of degree-days [1]. Therefore, there is a difference with Spanish climate zoning which takes into account sun's radiation, as well.

2.2.2 Characterization of requirements:

Depending on the type of building analyzed and on the intervention performed, maximum transmittances permitted by Italian decree 195/05 may vary. Therefore, in order to apply the decree, first a building and an intervention classification must be done.

2.2.2.1 Building classification:

Italian regulation divides buildings according to their use. So, according to the regulation DPR 412/93 these are the possible classes:

Building class	
E.1 (1)	Residential buildings with continued occupation.
E.1 (2)	Residential buildings with casual occupation.
E.1 (3)	Hotels, Hostels and similar buildings.
E.2	Office buildings.
E.3	Hospitals, churches and clinics.
E.4	Recreational purpose buildings.
E.5	Commercial Centres.
E.6	Sports purpose buildings.
E.7	Schools or Universities.
E.8	Industries, warehouses.

Chart 2-2.1. Building classification.

2.2.2.2. Type of intervention performed.

All the possible interventions performed to a new or existing building are classified by decree 195/05 on the following chart;

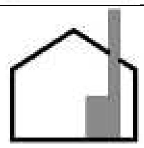
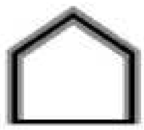
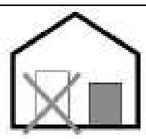
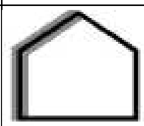
Type of intervention performed			
	Buildings of new construction.		Enlargement of an existing building to a volume greater than 20% of the building itself.
	New heating/cooling systems installation or heating/cooling systems change.		Total restoration of building's thermal envelope.
	New heating system installation.		Building's envelope partial restoration.

Chart 2-2.2. Type of intervention.

Decree 192/05, classifies all buildings according to the intervention performed and the building class. This classification is represented in chart 2-2.3.

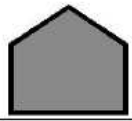
						
E1(1)	A, C, D, E, F, H, I, J, K, L	A, C, D, E, F, H, I, L	A, C, D, E, F, H, I	B, E, F, H, I	H, J, K, O, P	O, P, Q
E1(2)						
E1(3)						
E2	A, C, D, E, G, H, I, J, K, L	A, C, D, E, G, H, I, L	A, C, D, E, G, H, I	B, E, G, H, I		
E3						
E4						
E5						
E7						
E6	A, C, D, H, J, K, L	A, C, D, H, L	A, C, D, H	B, H		
E8	A, H, J, K, L	A, H, L	A, H			

Chart 2-2.3. Building classification

2.2.2.3 Building's energy requirements:

Depending on the building class, according to the classification detailed on sections 2.2.2.1 and 2.2.2.2, and to the shape factor (S/V)* of the building, maximum energy requirements **(ER_{lim})** expressed in kWh/m^{2}year are limited to:

*Were: S is the total surface of the façade and roof.

V is the net volume of the building wrapped by building's thermal envelope.

For residential buildings of the class E1 (chart 2-2.1. Building classification). Limits set for year 2008:

S/V	**Zona climatica**									
	A	B		C		D		E		F
	<600 GG	601 GG	900 GG	901 GG	1400 GG	1401 GG	2100 GG	2101 GG	3000 GG	>3000 GG
≤0.2	**10**	**10**	**15**	**15**	**25**	**25**	**40**	**40**	**55**	**55**
≥0.9	**45**	**45**	**60**	**60**	**85**	**85**	**110**	**110**	**145**	**145**

Chart 2-2.4. Maximum energy requirements **(ER_{lim})** for buildings of class E1 set for year 2008.

Limits set for year 2010:

S/V	Zona climatica									
	A	B		C		D		E		F
	<600 GG	601 GG	900 GG	901 GG	1400 GG	1401 GG	2100 GG	2101 GG	3000 GG	>3000 GG
≤0.2	**8.5**	**8.5**	**12.8**	**12.8**	**21.3**	**21.3**	**34**	**34**	**46.8**	**46.8**
≥0.9	**36**	**36**	**48**	**48**	**68**	**68**	**88**	**88**	**116**	**116**

Chart 2-2.5. Maximum energy requirements **(ER_{lim})** for buildings of class E1 set for year 2010.

All other buildings which are not included in class E1:

Limits set for year 2008:

S/V	Zona climatica									
	A	B		C		D		E		F
	<600 GG	601 GG	900 GG	901 GG	1400 GG	1401 GG	2100 GG	2101 GG	3000 GG	>3000 GG
≤0.2	**2.5**	**2.5**	**4.5**	**4.5**	**6.5**	**6.5**	**10.5**	**10.5**	**14.5**	**14.5**
≥0.9	**9**	**9**	**14**	**14**	**20**	**20**	**26**	**26**	**36**	**36**

Chart 2-2.6. Building's maximum energy requirements **(ER_{lim})** set for the year 2008.

Limits set for the year 2010.

S/V	Zona climatica									
	A	B		C		D		E		F
	<600 GG	601 GG	900 GG	901 GG	1400 GG	1401 GG	2100 GG	2101 GG	3000 GG	>3000 GG
≤0.2	**2**	**2**	**3.6**	**3.6**	**6**	**6**	**9.6**	**9.6**	**12.7**	**12.7**
≥0.9	**8.2**	**8.2**	**12.8**	**12.8**	**17.3**	**17.3**	**22.5**	**22.5**	**31**	**31**

Chart 2-2.7. Building's maximum energy requirements **(ER_{lim})** set for the year 2010.

Depending on the climate zone, maximum transmittances of the structures for the year 2008 are limited to:

Vertical walls:

TABELLA 2.1	**Strutture opache verticali**, Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.85	0.72	0.62
B	0.64	0.54	0.48
C	0.57	0.46	0.40
D	0.50	0.40	0.36
E	0.46	0.37	0.34
F	0.44	0.35	0.33

Chart 2-2.8. Vertical walls maximum transmittance for the year 2008.

Roof:

TABELLA 3.1	**Coperture** Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.80	0.42	0.38
B	0.60	0.42	0.38
C	0.55	0.42	0.38
D	0.46	0.35	0.32
E	0.43	0.32	0.30
F	0.41	0.31	0.29

Chart 2-2.9. Roof maximum transmittance for the year 2008.

Floor:

TABELLA 3.2	**Pavimenti verso locali non riscaldati o verso l'esterno** Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.80	0.74	0.65
B	0.60	0.55	0.49
C	0.55	0.49	0.42
D	0.46	0.41	0.36
E	0.43	0.38	0.33
F	0.41	0.36	0.32

Chart 2-2.10. Floor maximum transmittance for the year 2008.

Glazing:

TABELLA 4.a	Chiusure trasparenti Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	5.5	5.0	4.6
B	4.0	3.6	3.0
C	3.3	3.0	2.6
D	3.1	2.8	2.4
E	2.8	2.4	2.2
F	2.4	2.2	2.0

Chart 2-2.11. Glazing maximum transmittance for the year 2008.

Windows:

TABELLA 4.b	Vetri Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 luglio 2008** U (W/m^2K)	**Dall' 1 gennaio 2011** U (W/m^2K)
A	5.0	4.5	3.7
B	4.0	3.4	2.7
C	3.0	2.3	2.1
D	2.6	2.1	1.9
E	2.4	1.9	1.7
F	2.3	1.7	1.3

Chart 2-2.12. Windows maximum transmittance for the year 2008.

2.2.3 Previous data.

2.2.3.1 Climatic zoning.

Italian law classifies the country into six different climatic zones depending on the degree-days.
The chart used to classify climatic zones for the cities selected on this project can be found at the references[6]. It has not been included because is too extended to be on a appendix (approximately 63 pages).

2.2.3.2 Definition of thermal zone.

If it is taken on to consideration a closet volume which is acclimatized at a preset temperature, this is a **acclimatized volume** according to the definition on the Italian regulation. If this volume is acclimatized by an unique heating, cooling or ventilating device, this is known as **thermal zone** according with the regulation [5].

A unique thermal zone must fulfil the following requirements:

- Heating preset-temperatures cannot exceed a difference of 4º.
- Either cooling is not used, or cooling preset-temperatures cannot exceed a difference of 4º.
- The different rooms existing inside a thermal zone have to be powered by the same heating-cooling system.

2.2.4. Procedure.

The procedure followed is divided into the following stages:

- **Building classification:** Buildings must be classified depending on their future purpose (chart 2-2.1), and the intervention performed (figure 2-2.2), according to the classification of the chart 2-2.3.
- **Climatic zones classification:** Buildings must be placed in any of the six climatic zones defined by Italian regulation.
- **Maximum transmittance values permitted:** According to the type of building, the climatic zone and $\frac{glazzing\_surface}{useful\_area}$ ratio, two different options may be applied:

Option A:

The transmittances of the building envelope are limited to the values shown in charts 2-2.8, 2-2.9, 2-2.10, 2-2.11 and 2-2.12 increased a 30%.

Option B: For buildings with a $\frac{glazzing\_surface}{useful\_area}$ ratio lower than 0.18 the maximum energy requirements **(ER_{lim})** may be taken and maximum transmittances of the different structures will be limited to the values shown in charts 2-2.8, 2-2.9, 2-2.10, 2-2.11 and 2-2.12:

Since the $\frac{glazzing\_surface}{useful\_area}$ ratio of the building studied in this project equals:

$\frac{glazzing\_surface = 23,4m^2}{useful\_area = 149,55m^2} = 0,1564$, which is less than 0,18 this option will be the chosen to carry out this study. So, maximum energy requirements will be taken **(ER_{lim}).**

- **Maximum energy requirements permitted:** Energy requirements will be limited to: Depending on the option taken (glazing surface/useful area. ratio):

Option A: $ER \leq ER_{\lim}$ Building's heating energy requirements must be lower than the maximum values permitted. $ER \leq ER_{\lim}$ (Chart 2-2.4).

Option B: Maximum energy requirements may be taken. So $ER = ER_{\lim}$.

2.3. Spanish regulation:

2.3.1. Introduction:

The transposition of European Directive 2002/91/EC (EPBD) into the national law of member states of the European Union has signified the appearance of new and more onerous requirements in terms of construction quality from the point of view of energy performance and in terms of the procedure for certification of the energy performance of buildings. [2]

In Spain, this transposition was effected by Royal Decree 314/2006 of 17 March [2] approving the Technical Building Code (Codigo Tecnico de la Edificacion) which modifies the previous energy code NBE-CT-79, and Royal Decree 47/2007, of 19 January [3], approving the basic procedure for certification of the energy performance of new buildings.[2]

Both the new energy performance requirements established by Royal Decree 314/2006 in Section HE-1 on Energy Demand Limitation of Buildings and the procedure for certification of the energy performance of buildings are determined according to the climatic variability of 12 different climatic zones.[2]

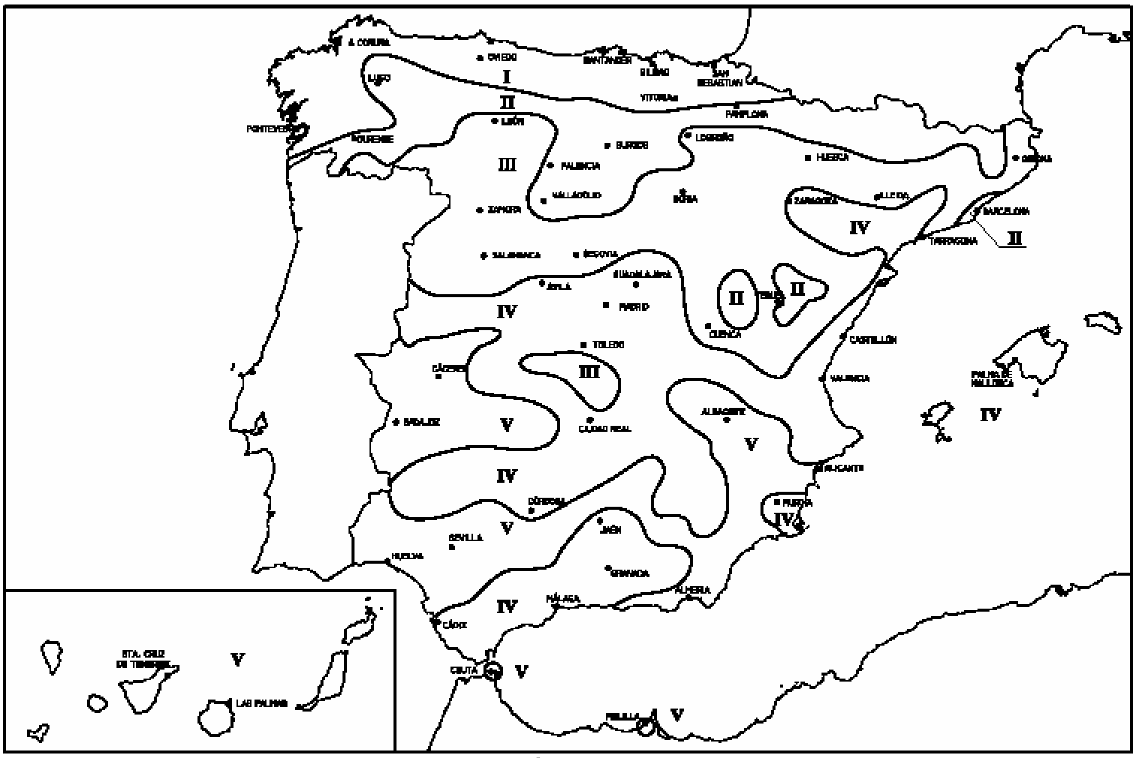


Figure 2-3.1. Climatic zones in Spain.

In figure 2-3.1 all climatic zones in which Spain has been divided are included. This map gives a general idea of Spain’s climate zoning though, in order to have a better accuracy, all the cities existing in Spain are included with their climate zone in a chart at the appendix.

In the case of Spain, energy saving law in buildings is regulated by CTE. This document has as a main target the regulation of laws and proceedings which enable fulfill the basic requirements on energy saving. This document was written on 19th October 2007 and corrected and updated on 25th January 2008.

Although this document is composed by five different regulations related to the European directive 2002/91/EC, we will focus on the first one: “Energy requirement limitations”, which is the one necessary to carry out this study.

Basically, this standard has as main objective to ensure that buildings have a thermal envelope which limits properly theirs energy requirements needed to have the desired thermal comfort. This have to be done taking into account building future purpose, the climate zoning, thermal inertia, solar radiation and the possible heat leakages through infiltrations.

This regulation must be applied to:

- Buildings of new construction.
- Buildings with an useful surface greater than 1000 m^2, which are under major interventions, in which more than a 25% of the building envelope is changed.

Procedure:

There are two possible procedures than can be applied in order to fulfil the regulation:

Simplified procedure: which is based on an indirect control over the energy required, i.e. Building’s energy requirements are limited by controlling of building’s thermal envelope characteristics. Depending on each climate zone in which the building is supposed to be built, the transmittances of the different parts of building’s envelope, should not exceed a certain value that is regulated by the standards.

General proceeding: This proceeding is based on the direct control of building's energy requirements. The energy required is compared with energy requirements needed by a sample building which are previously defined.

For both proceedings condensations which may appear on inside surfaces should be avoided, a control and limitation of possible infiltrations which could become an energy waste should be applied, as well.

On this project, taking into account the experimental principles of it, simplified proceeding will be applied because we can only have an indirect control over the energy requirements while running simulations, by setting building's envelope characteristics.

2.3.2 Characterization of requirements:

2.3.2.1 Energy demand:

Energy demand of buildings is limited depending on the climatic zone in which they are placed. With the simplified proceeding, this will be done by setting maximum transmittances permitted by the regulation depending on the thermal zone. Following this procedure, the Spanish energy regulations classify the 52 provincial capitals into 12 climatic zones, identified by a letter from A to E and a number from 1 to 4. The letter refers to the winter climatic zoning, while the number refers to the summer climatic zoning.

Simplified proceeding

The parameters which define building thermal envelope are:

U_M Vertical walls transmittance.
U_C Roof transmittance.
U_S Floor transmittance.
U_H Glazing transmittance.

Depending on the climate zone, these transmittances will have a maximum value (U_{Mlim} U_{Clim} U_{Slim} U_{Hlim}) permitted by the regulation. Enclosed to this project, there an appendix which details these values according to the CTE and a chart with the climatic zones existing in Spain.

CTE also establishes the maximum transmittances permitted between two volumes at different temperature existing inside the building's thermal envelope. We will not include these values because the building which it is being studied has all rooms at approximately the same temperature, so there is no need to include them.

2.3.2.2 Infiltrations:

CTE specifies maximum volume that can be exchanged through the holes, (such as windows and doors), located at building's envelope.

Since this infiltrations become a heat loss, this permeability is regulated, depending on the thermal zone, following the specifications of thermal zoning in Spain. Knowing this, two different maximum values for the possible infiltrations will be permitted.
These values measured with an overpressure of 100 Pa will be limited to:

- For climatic zones A and B: 50 m^3/hour per square meter of façade.
- For climatic zones C, D and E: 27 m^3/hour per square meter of façade.

2.3.3. Previous data:

2.3.3.1 Climatic zoning.

As explained above, there are 12 climatic zones in which the building can be placed. This zoning can be done of two different ways, either searching the city or town desired on the chart existing on the appendix, or calculating the zoning with existing climatic data records.

In our case, first procedure will be carried out. Thus, simulated cities will be selected on the chart existing in the appendix.

2.3.3.2 Spaces classification.

The following figure (2-3.2) shows all the different spaces may exist inside a residential building. There are habitable spaces which are supposed to be acclimatized, and non-habitable spaces which are not. This figure shows also, the different kinds of building's thermal envelope that can exist, such as tiled roofs attics, windows, floor, walls in contact with air, and walls in contact with terrain. In this project, knowing the characteristics of the building studied, only four kinds have been studied: horizontal roofs, vertical walls in contact with air, floor and vertical windows.

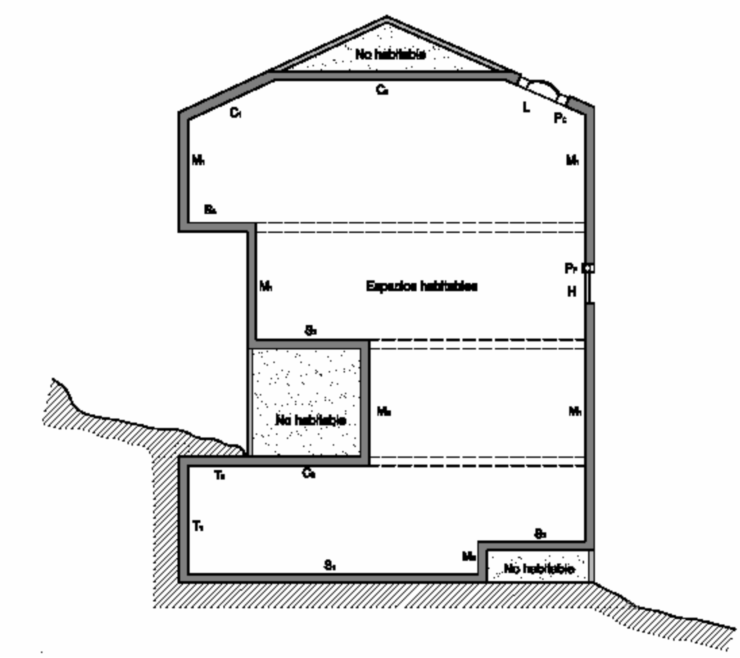


Figure 2-3.2. Building's thermal envelope.

2.3.4. Simplified proceeding:

2.3.4.1. Objectives:

Objectives of simplified proceeding are four:

- Restrict building's energy demand, by establishing maximum transmittance values U on the different parts of building's thermal envelope.
- Restrict the presence of condensation on the inner wall surfaces.
- Restrict infiltrations on building which may become a heat loss.

- In residential buildings, restrict heat exchange between acclimatized areas and non-acclimatized.

2.3.4.2 Maximum transmittance values permitted:

- Transmittance existing in vertical walls of a new building for each orientation, must be lower than the maximum transmittance permitted for vertical walls $U_{Mlim.}$
- Transmittance existing in floor of the a building must be lower than the maximum transmittance permitted for floors $U_{Slim.}$
- Transmittance existing in roof of the a building must be lower than the maximum transmittance permitted for roofs $U_{Clim..}$
- Transmittance existing in windows of a new building, depending on the holes proportion on the façade and the orientation, must be lower than the maximum transmittance permitted for windows $U_{Clim..}$

2.3.4.3 Maximum solar correction factors permitted:

- Maximum solar correction factor of glazing of windows depending on the holes proportion existing on the façade will be lower than the maximum permitted $F_{Hlim.}$

General proceeding will not be explained in detail since it is not necessary for this study.

3. REPORT ON THE SOFTWARE FOR THE VALUATION OF ENERGY PERFORMANCE OF BUILDINGS.

3.1. Introduction:

In this section, we will describe the report written at University Degli Studi di Perugia (*Rapporto sull'analisi di codici di calcolo per la valutazione energetica degli edifici*. Perugia. September 2008)[1] about the state-of-the-art in validation of energy performance of buildings. The hypothesis and the results reached in this report have been taken as a guide to carry out and compare to the current study on TRNSYS. The descriptions of the test building and its boundary conditions defined in this report, have been introduced on TRNSYS. So, first of all, a description of this report should be detailed.

This section pretends to be a summary of the report mentioned in the previous paragraph, so is focused on some parts that have been considered important, others have been omitted. To have the complete information about the report please, refer to the original.

3.2. Description of the report:

The research has been divided into three different phases:

Phase 1:

Objective: Simulation with the different software selected starting from simplified inputs. According to this, during the simulations thermal characteristics of the different components of building's envelope have been introduced, thermal bridges have been considered negligible and not introduced. A heating system with a power of 6 kW with different performances, which vary according to the different climatic zones studied, has been introduced.

Phase 2:

Objective: Simulation with the different software selected considering also, linear thermal bridges during building's energy performance in winter.

To do this, the same characteristics of the building's thermal envelope taken in the phase 1 have been considered, and this time, the heating system has a power of 10kW.

Phase 3:

Objective: Simulation with the different software selected considering different strategies of thermal insulation in winter.

This will be done by testing different insulation layers of building's thermal envelope.

In this study we will focus on the first two phases. The results of this report will be compared with the results obtained with TRNSYS.

All the simulations, for all these three phases, will be run according to the climatic data of the following cities:

In increasing order of climatic severity:

- Palermo
- Bari
- Roma
- Florence
- Milan

3.3. Software analyzed:

After classifying the procedure, a selection of the software used must be done. These are the programs chosen to perform the research.

1. MC IMPIANTO;
2. EC501;
3. MC4 Software;
4. BEES LITE;
5. PHPP 2007it;
6. CasaClima;
7. BESTCLASS;
8. Docet;
9. DESIGN BUILDER;
10. Ecotect;

Here, in the following chart (3.1), further information of the software selected is detailed:

Name	Nation	Authors	Web site
EC501	ITA	Edilclima	www.edilclima.it
MC4 Software	ITA	MC4 Software	www.mc4software.com
MC Impianto	ITA	Aemec	www.aermec.it
BEES LITE	ITA	Cellai, Bazzini, Gai	www.beelab.it
PHPP 2007it	GER-ITA	PHI-TBZ	**www.passiv**.de – **www.tbz**.bz
CasaClima	ITA	Provincia Autonoma di Bolzano	**www.agenziacasaclima**.it
BESTCLASS	ITA	Politecnico di Milano	**www.sacert**.eu
Docet	ITA	CNR/ Tecnologie della Costruzione – ENEA	**www.itc**.cnr.it – **www.enea**.it
Ecotect	UK	Centre for Research in the Built Environment	**www.squ**1.com
Design Builder	ITA	DesignBuilder Software Ltd.	**www.evolvente**.it

Chart 3.1. Software analyzed.

3.4. Description of the test building:

In order to avoid possible misunderstandings during the research, a test building with a simple geometry has been taken to perform all the simulations.

In the next figure, we enclose a plan of building's floor. Internal and external dimensions are also detailed.

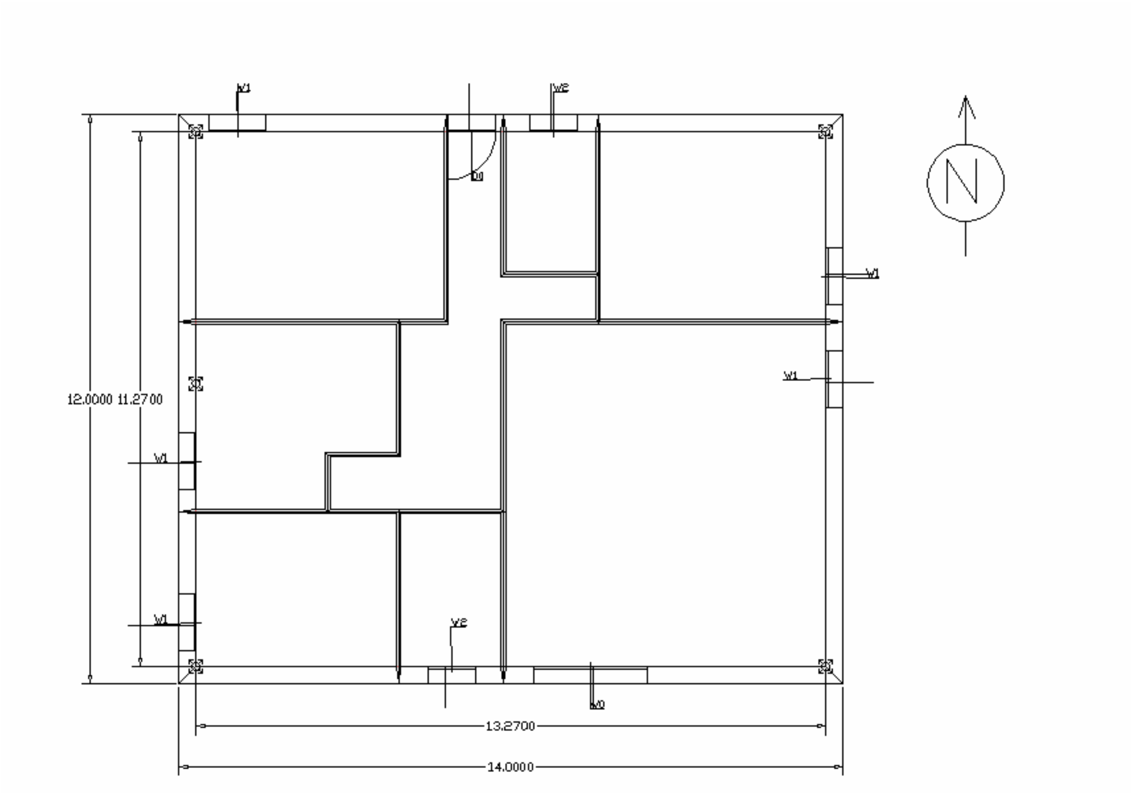
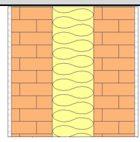
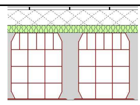


Fig.3.1 Test building dimensions.

- Building height equals 2,7m.

In this chart (3.2), the basic characteristics of building's thermal envelope are detailed:

Symbol	Definition	Value	Unit	Sketch
U_1	Transmittance of the external walls	0,246	W/m^{2}K	
U_2	Transmittance of the floor	0,378	W/m^{2}K	

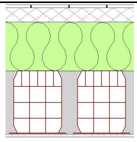
U_3	Transmittance of the roof	0,204	W/m^{2}K	
U_g	Transmittance of the glazing	1,60	W/m^{2}K	
g_{ORT}	g value	0,622	-	
U_f	Transmittance of window's frame	2,00	W/m^{2}K	
F_c	Mean shading factor	Not applicable		

Chart 3.2. Building's thermal envelope characteristics.

For phases I and II we will detail the description of the layer configuration existing in the different structures of the building's envelope. Phase III has been omitted because it has no interest for this project, since the values compared with TRNSYS are for phases I and II.

The calculation of the transmittance has been done according to the standard UNI 6946 and UNI 10346.

- Vertical walls:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m^3)	Specific heat (kJ/kgK)
External plaster	0,015	0,900	1800	0,84
Brick wall	0,12	0,260	600	0,84
Fibreglass	0,12	0,039	80	1,03
Brick wall	0,12	0,360	1000	0,84
Internal plaster	0,010	0,900	1800	0,84

Chart 3.3. Vertical walls configuration.

Total thickness: 0,385 m.

Total thermal transmittance:0,2460 W/m^{2}K.

Surface mass: 202 kg/m^2

External colour: Bright.

- Roof:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m^3)	Specific heat (kJ/kgK)
Tile	0,01	0,720	1800	0,84
Concrete	0,05	0,930	1800	0,88
Expanded polyethylene	0,21	0,048	33	1,45
Cement	0,22	0,700	1450	0,84
Internal plaster	0,010	1,400	2000	0,84

Chart 3.4. Roof layer configuration.

Total thickness: 0,5 m

Total thermal transmittance:0,2040 W/m^{2}K.

Surface mass: 434 kg/m^2

External colour: Medium.

- Floor:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m3)	Specific heat (kJ/kgK)
Cement	0,22	0,7	1450	0,84
Extruded polystyrene	0,08	0,039	25	1,25
Concrete	0,05	0,930	1800	0,88
Tile	0,01	0,720	1800	0,84

Chart 3.5. Floor layer configuration

Total thickness: 0,360 m

Total thermal transmittance:0,3780 W/m^{2}K.

Surface mass: 429 kg/m^2

External colour: Not applicable.

Here, geometry of windows is reported:

Window	Dimensions	Uw (W/m^{2}K)
F1	120x250	1,931
F2	60x150	2,206
F3	100x150	2,009
F4	240x250	1,864

Chart 3.6. Windows geometry.

Besides these characteristics, all the windows will have the following in common:

- Single window (no spacer).
- Air permeability: according to the class A3 UNI 7979/class 4 UNI EN12207;
- Frame thickness: 70 mm;
- No container.
- No shading.

Now, the characteristics of the heating system are defined (chart 3.7):

Ventilation system	Mechanical Ventilation	Not introduced			
	Hourly air change	0,3 vol/h			
Heating system	Heat generator	Standard boiler			
	Heating system power and performance. 1st Phase. Depending on the location studied.	City	Power	η_{pump}	$\eta_{Generator}$
		Milan	6kW	0,92	0,83
		Rome	6kW	0,90	0,81
		Bari	6kW	0.90	0.81
		Palermo	6kW	0,87	0,79
		Florence	6kW	0,91	0,82
	Heating system power and performance. 2nd Phase. Depending on the location studied	City	Power	η_{pump}	$\eta_{Generator}$
		Milan	10kW	0,93	0,84
		Rome	10kW	0,92	0,83
		Bari	10kW	0.92	0.83
		Palermo	10kW	0,91	0,82
		Florence	10kW	0,92	0,83
Hot water system	Installation for the production of hot water	Not considered			
Renewable energy sources	Solar systems	Not introduced			

Chart 3.7. Characteristics of the heating system.

3.5. Further boundary conditions:

Here, further boundary conditions required by the software to calculate heating loss through the floor and thermal bridges are defined:

Thermal bridges:

Heating loss caused by thermal bridges has been calculated according to the European normative UNI EN ISO 14683. Only linear thermal bridges have been taken into consideration, point thermal bridges have been considered negligible.

The following figure, shows the typical locations of linear thermal bridges. The capital letters against each thermal bridge denote the type of thermal bridge and the suffix denotes the specific thermal bridge, e.g. IW_n denotes one thermal bridge at the junction of the external envelope with an internal wall and IW_m denotes another different thermal bridge of the same type [2].

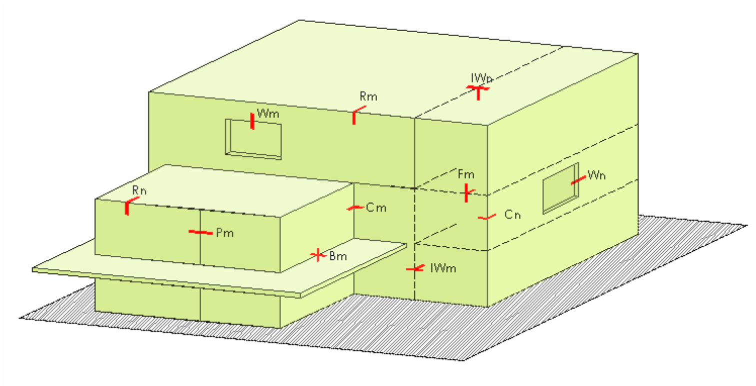


Fig.3.2 Potential thermal bridges existing in a specific building.

In the phase II thermal bridges will be considered, so we define linear transmittance Ψ in (W/mK) according to the normative UNI EN ISO 14683. The next chart (3.8) shows the values taken from European regulation on thermal bridges in building construction.

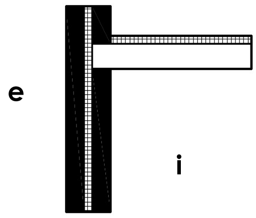
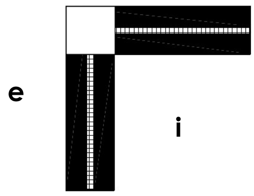
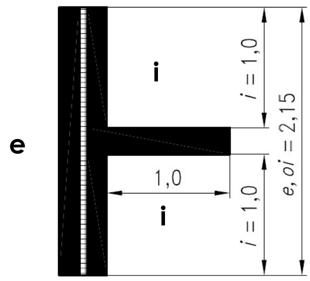
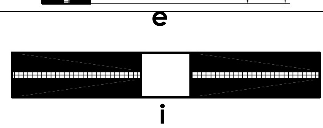
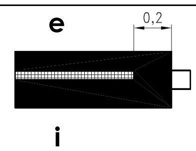
Class of thermal bridge	Linear transmittance ψ (W/mK)	Thermal bridge length* (m)	Graphic sketch
Roofs and floor. (UNI EN ISO 14683 - R6)	ψ_e = 0,40 ψ_{oi} = 0,55 ψ_i = 0,55	Roof: 2x48,92 Floor: 2x48,92	
Corners (UNI EN ISO 14683 - C2 - EUROKOBRA)	ψ_e = 0,70 ψ_{oi} = 0,90 ψ_i = 0,90	N=S=E=O: 2x2,70	
Internal walls (UNI EN ISO 14683 - IW5)	ψ_e = 0,00 ψ_{oi} = 0,00 ψ_i = 0,05	N: 6x2,70 S=O: 4x2,70 E: 2x2,70	
Pillars (UNI EN ISO 14683 - P2)	ψ_e = 1,20 ψ_{oi} = 1,20 ψ_i = 1,20	N=S=E=O: 4x2,70	
Window and door openings (UNI EN ISO 14683 - W8)	ψ_e = 0,60 ψ_{oi} = 0,60 ψ_i = 0,60	N: 7,40x2+4,20 S: 5,00+9,80 O=E: 7,40x2	
* = Internal length			

Chart 3.8. Thermal bridges characteristics.

Were: - Ψ_i is based on internal dimensions.

- Ψ_{Oi} is based on overall internal dimensions.
- Ψ_e is based on external dimensions.

Floor:

Building's floor transmittance has been defined previously with a transmittance value of 0,378 W/m^{2}K, but if we consider this floor settled on the ground, this transmittance will became to a value of 0,238 W/m^{2}K according to the regulation UNI EN ISO 13370.

Other characteristics of the ground:

- Ground category: Sand/gravel.
- Ground's conductivity: 2 W/mK.
- Ground's temperature: 12,5 ºC.

Gains:

Internal gains have been calculated according to the recommendation CTI-03:

For residential buildings with an useful area not bigger than 200 m^2 is recommended to take:

$Internal\_gains = 6,25 - 0,02 \cdot S \left(\frac{W}{m^2} \right)$.Where S is the internal area in square meters. So;

For an internal surface of $S = (11,27 \cdot 13,27)\, m^2$; Internal gains = 3,278 W/m^2

3.6. Results:

Here, the results obtained during the simulations are presented:

The results are given for each phase of the study and city simulated (Palermo, Bari, Roma, Florence, Milan) in $\frac{kWh}{m^2 of.useful.surface \cdot year}$ of energy requirements for heating.

Results for phase 1:

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
MC IMPIANTO	UNI. Italian Laws. 311/2006	Milan	41,18
		Florence	27,93
		Roma	17,86
		Bari	14,04
		Palermo	6,87

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
EC501	UNI. Italian Laws. 311/2006	Milan	38,52
		Florence	25,35
		Roma	15,05
		Bari	11,62
		Palermo	5,28

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
MC4 SOFTWARE	UNI. Italian Laws. 311/2006	Milan	34,52
		Florence	19,37
		Roma	13,38
		Bari	8,71
		Palermo	5,40

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
BEES_LITE	UNI. Italian Laws. 311/2006	Milan	37,77
		Florence	24,97
		Roma	13,52
		Bari	11,14
		Palermo	4,30

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
PHPP 2007it	UNI EN 13790	Milan	71
		Florence	39
		Roma	22
		Bari	29
		Palermo	3

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
CasaClima	UNI EN 832	Milan	68,83
		Florence	43,65
		Roma	25,21
		Bari	21,35
		Palermo	8,00

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
BestClass	UNI EN 832	Milan	61,92
		Florence	45,71
		Roma	31,30
		Bari	24,97
		Palermo	12,37

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
DOCET	UNI 13790 (Simplified)	Milan	78,9
		Florence	58,8
		Roma	42,1
		Bari	34,2
		Palermo	20,2

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
DesignBuilder	Transfer function and ASHRAE “Heat balance”	Milan	39,62
		Florence	26,02
		Roma	18,22
		Bari	14,88
		Palermo	3,95

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
Ecotect 5.5	“Metodo dell'ammettenza (CIBSE)”	Milan	47,12
		Florence	28,92
		Roma	26,81
		Bari	21,42
		Palermo	9,41

<u>Results for phase 2:</u>

In the phase 2 basically, the same characteristics of building’s envelope as the phase 1 have been introduced, but in this phase also the thermal bridges have been simulated. Also, the power of the heating system has been switched from 6 kW to 10 kW.

In this phase, some of the software detailed previously has been omitted because not all the software studied is able to simulate linear thermal bridges. In the following charts the results of the phase 2 are presented:

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
MC IMPIANTO	UNI. Italian Laws. 311/2006	Milan	128,10
		Florence	94,25
		Roma	68,51
		Bari	57,37
		Palermo	33,29

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
EC501	UNI. Italian Laws. 311/2006	Milan	100,52
		Florence	72,21
		Roma	50,90
		Bari	42,48
		Palermo	23,11

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
MC4 SOFTWARE	UNI. Italian Laws. 311/2006	Milan	78,13
		Florence	52,16
		Roma	33,36
		Bari	25,43
		Palermo	10,61

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
BEES_LITE	UNI. Italian Laws. 311/2006	Milan	105,60
		Florence	79,93
		Roma	57,60
		Bari	47,51
		Palermo	28,63

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
PHPP 2007it	UNI EN 13790	Milan	143
		Florence	85
		Roma	55
		Bari	69
		Palermo	13

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
CasaClima	UNI EN 832	Milan	173
		Florence	123
		Roma	86
		Bari	72
		Palermo	38

Software used	Regulation followed	City	Specific energy requirements (kWh/m^{2}year)
BestClass	UNI EN 832	Milan	91,10
		Florence	69,51
		Roma	51,00
		Bari	40,23
		Palermo	23,24

Note: During this report winter heating requirements of a test building have been obtained. There are discrepancies between the results obtained. One of the purposes of this project is to compare these results with the ones obtained on a simulation under the same inputs, but carried out with the software TRNSYS. This will be done in the chapter 6 of this project.

4.DESCRIPTION OF TRNSYS

This chapter is made up of two parts. The first one, will be a description in which the basic mathematical procedure followed by TRNSYS will be explained. The second part will explain the procedure followed during the implementation of the simulation on TRNSYS.

4.1 TRNSYS mathematical description.

This section is focused on the mathematical description of the program used during the simulations, which is TRNSYS. Most of the documentation used to explain this section comes from TRNSYS user's handbook. Although the documentation existing on this manual is quite extended, here we have tried to summarize the basic mathematical principles that TRNSYS has used to carry out the simulations. Thus, there are a lot of parts from the handbook omitted. The extended mathematical description of the multizone building can be found at the chapter 6 of TRNSYS user's handbook.

4.1.1 Thermal zone:

The building model in TRNSYS is a non-geometrical balance model with one air node per zone, representing thermal capacity and air volume of the zone.

TRNSYS executes an energy balance on each node *i*:

$$\dot{Q}_i = \dot{Q}_{surf,i} + \dot{Q}_{\inf,i} + \dot{Q}_{vent} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i} \qquad \text{Eq.4-1.1}$$

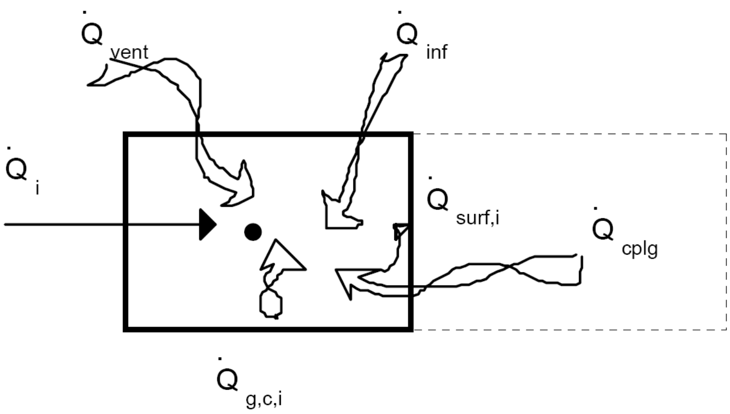


Figure 4-1.1. Heat balance on the zone air node. (TRNSYS user's Handbook)

Figure 4-1.1 represents the heat balance on the thermal zone air node, all the possible heat sources are included in the image, where:

$\dot{Q}_{\inf,i}$ are the infiltration gains or loss, (air flow coming in from outside) given by:

$$\dot{Q}_{\inf,i} = \dot{V} \cdot \rho \cdot c_p \cdot (T_{outside} - T_{air});$$ Eq.4-1.2

$\dot{Q}_{vent,i}$ are the ventilation gains. Given by:

$$\dot{Q}_{vent,i} = \dot{V} \cdot \rho \cdot c_p \cdot (T_{ventilation,i} - T_{air});$$ Eq. 4-1.3

$\dot{Q}_{g,c,i}$ are the internal convective gains.

$\dot{Q}_{cp\lg,i}$ are the gains due to connective air flow from thermal zone I or boundary condition. Given by:

$$\dot{Q}_{cp\lg,i} = \dot{V} \cdot \rho \cdot c_p \cdot (T_{zone,i} - T_{air});$$ Eq. 4-1.4

$\dot{Q}_{surf,i}$ are the total gains from surfaces to a zone.

From now on, each part of the equation **4-1.1.**will be developed:

4.1.1.1 Infiltration, ventilation and convective coupling ($\dot{Q}_{\inf,i}$, $\dot{Q}_{vent,i}$, $\dot{Q}_{cp\lg,i}$).

On TRNSYS, infiltration rates must be specified as volume air changes per hour for each zone i.e. [vol/h] or [1/h]. The mass flow rate is the product of the zone air volume, the infiltration or ventilation rate and air density i.e.

Mass flow rate [kg/h] = air density [kg/m^3]· zone air volume [m^3]· infiltration rate [1/h].

The difference between infiltration and ventilation is that infiltration occurs always from the outside (with outside properties; temperature, density…) and ventilation occurs from a specified conditions. As the air enters inside a thermal zone, equal amounts of air are assumed to leave the zone, at the zone temperature.

TRNSYS calculates the energy gains due infiltration and ventilation in any node *i*:

$$\dot{Q}_{\inf,i} = \dot{m}_{\inf,i} \cdot C_p \cdot (T_a - T_i)$$ Eq.4-1.5

$$Q_{vent.i} = \sum_{k}^{nvent} \dot{m}_{vent,k,i} \cdot C_p \cdot (T_{vent,k} - T_i)$$ Eq.4-1.6

Where:

$\dot{m}_{\inf,i}$ is the mass flow rate of infiltration air.

$\dot{m}_{vent,k,i}$ is the mass flow rate of ventilation air of ventilation type *k.*

C_p is the specific heat of the air.

$T_{vent,k}$ is the temperature of ventilation air of ventilation type *k.*

T_a is the ambient air temperature.

For each wall or window that separates two thermal zones at different temperatures is possible to establish a convective coupling. This, is the mass flow rate that enters the zone across the surface. An equal amount of air is supposed to leave the zone at its temperature. The energy balance due the convective coupling can be expressed as:

$$\dot{Q}_{cp\lg,i} = \sum^{adj.zones} \sum^{surfaces.sito.j} \dot{m}_{cp\lg,s} \cdot C_p \cdot (T_j - T_i) + ... + \sum^{knownbound} \dot{m}_{cp\lg,s}\, Cp \cdot (T_{b,s} - T_i) \quad \text{Eq.4-1.7}$$

Where $\dot{m}_{cp\lg,s}$ is the mass flow that enters to the zone.

Note: TRNSYS enables us to define various types of ventilation, heating, cooling, etc, at the window *manager*. The letter *k* identifies the several existing types.

4.1.1.2 Internal convective gains ($\dot{Q}_{g,c,i}$).

These gains are user-defined on TRNBuild. TRNSYS gives a default value for these gains which can be edited with TRNBuild.

4.1.1.3 Total gains from surfaces (walls and windows) in a zone ($\dot{Q}_{surf,i}$).

The total gain to a zone i from all surfaces, is the sum of the combined heat transfers. TRNSYS solves the following equation:

$$\dot{Q}surf,i = \sum Ai \cdot \dot{q}_{comb,i} = \sum_{j=1}^{Adj.Zones} \sum_{i=1}^{surface.ito.j} A_s \cdot B_s \cdot T_{star,j}$$

$$+ \sum_{i=1}^{ext.surfaces} A_s \cdot B_s \cdot T_a + \sum^{\text{int}.walls} A_s \cdot B_s \cdot T_{star} + \sum^{known.bound} A_s \cdot B_s \cdot T_{b,s} - \sum^{\substack{surface\\in.zone.i}} A_s \cdot (C_s \cdot T_{star,j} - D_s - S_{s,i}$$

Equation 4-1.8

Were A_s is the inside area of the surface *s*.

Now, components of equation 4-1.8; B_s, Cs, Ds, T_{star}, T_b are defined:

- Radiative heat flows to the walls and windows:

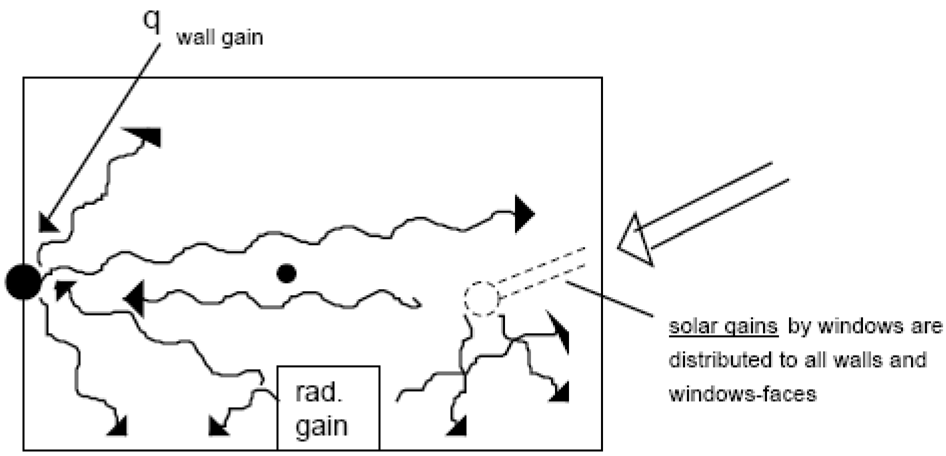


Figure 4-1.2. Radiative energy flows considering one wall with its surface temperature node. (TRNSYS user's Handbook)

Figure 4-1.2 shows the radiative flows on one wall. An energy balance would be:

$$\dot{Q}_{r,wi} = \dot{Q}_{g,r,i,w_i} + \dot{Q}_{sol,w_i} + \dot{Q}_{long,w_i} + \dot{Q}_{wall-gain} \qquad \text{Eq.4-1.9}$$

Were:

$\dot{Q}_{r,wi}$ is the radiative gain for the wall surface temperature node.

$\dot{Q}_{g,r,i,w_i}$ is the radiative zone internal gains received by a wall.

$\dot{Q}_{sol,w_i}$ is the solar gain through zone windows received by the walls.

$\dot{Q}_{long,w_i}$ is the longwave radiation exchange between this wall and all the other walls and windows.

$\dot{Q}_{wall-gain}$ is the user-defined heat flow to the wall or window surface.

- Integration of walls and windows.

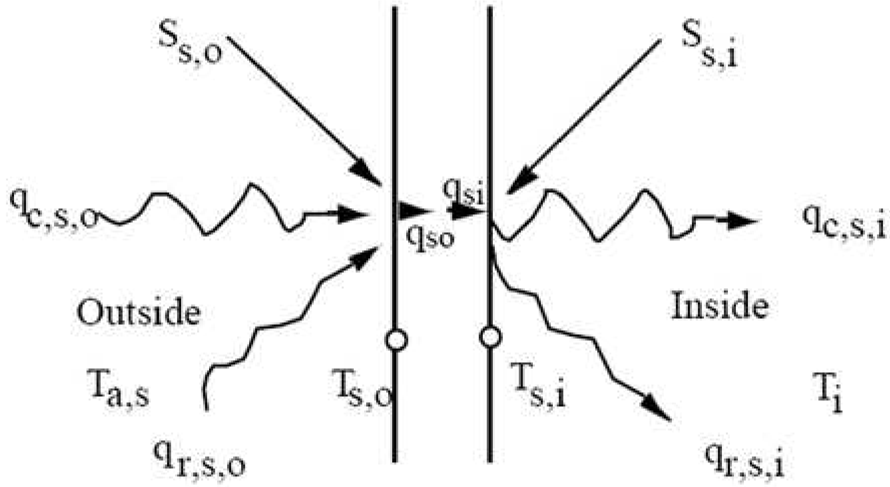


Figure 4-1.3. Surface heat fluxes and temperatures. (TRNSYS user's Handbook).

This figure shows the heat fluxes and temperatures that characterize the thermal behavior of any wall or window. Were;

$S_{s,i}$ Radiation heat flux absorbed at the inside surface (solar and radiative gains).

$S_{s,o}$ Radiation heat flux absorbed at the outside surface (solar gains).

$\dot{q}_{r,s,i}$ Net radiative heat transfer with all other surfaces within the zone.

$\dot{q}_{r,s,o}$ Net radiative heat transfer with all surfaces in view of the outside surface.

$\dot{q}_{w,g,i}$ User defined heat flux to the wall or window surface.

$\dot{q}_{s,i}$ Conduction heat flux from the wall at the inside surface.

$\dot{q}_{s,o}$ Conduction heat flux from the wall at the outside surface.

$\dot{q}_{c,s,i}$ Convection heat flux from the inside surface to the zone air.

$\dot{q}_{c,s,o}$ Convection heat flux to the outside surface from the boundary/ambient.

$T_{s,i}$ Inside surface temperature.

$T_{s,o}$ Outside surface temperature.

The walls are modelled according to the transfer function relationships of Mitalas and Arseneault[3]. For any wall, the heat conduction at the surfaces are:

$$\dot{q}_{s,i} = \sum_{k=0}^{n_{b_s}} b_s^k T_{s,o}^k - \sum_{k=0}^{n_{c_s}} c_s^k T_{s,i}^k - \sum_{k=1}^{n_{d_s}} d_s^k \dot{q}_{s,i}^k \qquad \text{Eq. 4-1.10}$$

$$\dot{q}_{s,0} = \sum_{k=0}^{n_{a_s}} a_s^k T_{s,o}^k - \sum_{k=0}^{n_{b_s}} b_s^k T_{s,i}^k - \sum_{k=1}^{n_{d_s}} d_s^k \dot{q}_{s,0}^k \qquad \text{Eq. 4-1.11}$$

These time series equations in terms of surface temperatures and heat fluxes are evaluated at equal time intervals. The superscript *k* refers to the term in the time series. The current time is k=0, the previous time is k=1, etc. The time-base on which these calculations are based is specified by the user within the TRNBuild description. The coefficients of the time series (a's, b's, c's, and d's) are determined within the TRNBUILD program using the z-transfer function routines of reference [3].

Windows are thermally considered as an external walls with no thermal inertia, partially transparent to the light but opaque to long-wave internal gains. TRNSYS calculates the energy balance of a window through a 2-node model shown in the figure 4-1.4.
The equations 4-1.10 to 4-1.22 can be used to model a window with:

$$a_s^o = b_s^o = c_s^o = d_s^o = U_{g,s}$$

$$a_s^k = b_s^k = c_s^k = d_s^k = 0 \qquad \text{for k>0}$$

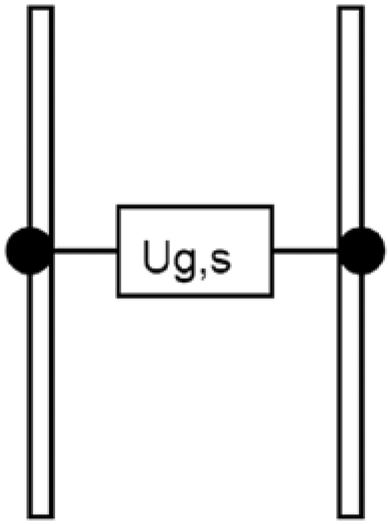


Figure 4-1.4 Two-node window used by TRNBuild to model thermal behaviour of windows.

- The Long-wave radiation.

The long-wave radiation exchange between the surfaces within the zone and the convective heat flux from the inside surfaces to the zone air are approximated using the star network given by seem [4].

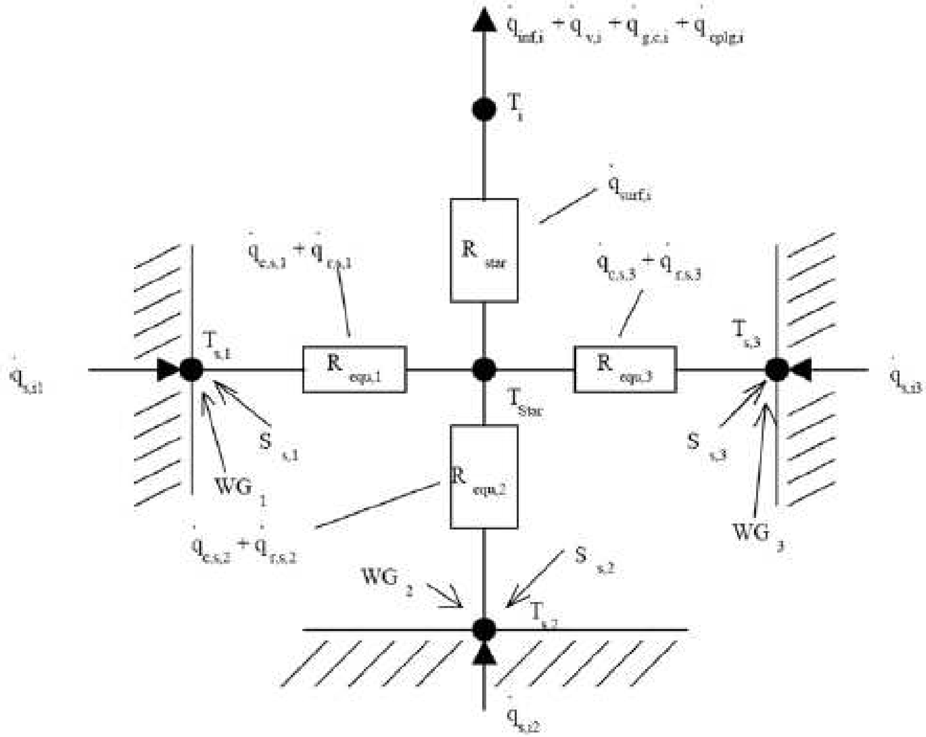


Figure 4-1.5. Star network for a zone with three surfaces.

In this figure, is represented the star network approximation for a zone with three surfaces. This method uses an artificial temperature node (T_{star}) to consider the parallel energy flow from a wall surface by convection to the air node and by radiation to other wall and window elements.

$$R_{star,i} = f(\alpha_i, A_{Surf}) = \frac{1}{Q_{surf,i}} \cdot (T_{star} - T_i) \qquad \text{Eq.4-1.12}$$

An energy balance on the star node of the figure 4-1.5 shows that:

$$Q_{surf,i} = \frac{1}{R_{star,i}} \cdot \left(T_{star,i} - T_i\right) \qquad \text{Eq. 4-1.13}$$

Methods to calculate the resistances *Requiv,i* and *Rstar,i* can be found at the reference [4]. The star temperature can be used to calculate a net radiative and convective heat flux from the inside wall surface:

$$\dot{q}_{comb,s,i} = \dot{q}_{c,s,i} + \dot{q}_{r,s,i} \qquad \text{Eq. 4-1.14}$$

then,

$$\dot{q}_{comb,s,i} = \frac{1}{R_{equiv,i} A_{s,i}} (T_{s,i} - T_{star}) \qquad \text{Eq. 4-1.15}$$

where $q_{comb_{s,i}}$ is the combined convective and radiative heat flux, and $A_{s,i}$ is the inside surface area.

For external surfaces the long-wave radiation exchange at the outside surface is considered explicitly using a fictive sky temperature, T_{Sky}, which is an input to TRNBuild and a view factor to the sky, f_{sky}, for each external surface. The total heat transfer is given by the sum of convective and radiative heat transfer:

With

$$\dot{q}_{c,s,o} = h_{conv,s,o}(T_{a,s} - T_{s,o}) \qquad \text{Eq. 4-1.16}$$

$$\dot{q}_{comb,s.o} = \dot{q}_{c,s,o} + \dot{q}_{r,s,o} \qquad \text{Eq. 4-1.17}$$

$$\dot{q}_{r,s,o} = \sigma\varepsilon_{s,o}(T_{s,o}{}^4 - T_{fsky}{}^4) \qquad \text{Eq. 4-1.18}$$

$$T_{fsky} = (1 - f_{sky})T_{a,s} + f_{sky}T_{sky} \qquad \text{Eq. 4-1.19}$$

Were:

$\dot{q}_{comb,s,o}$ is the combined convective and radiative heat flux to the surface.

$\dot{q}_{c,s,o}$ is the convective heat flux to the surface.

$\dot{q}_{r,s,o}$ is the radiative heat flux to the surface.

$h_{conv,s,o}$ is the convective heat transfer coefficient at the outside surface.

f_{sky} is the fraction of the sky seen by the outside surface.

T_{fsky} Fictive sky temperature used for long-wave radiation exchange.

$\varepsilon_{s,o}$ Long-wave emissivity of outside surface (ε=0,9 for walls).

σ Stephan-Boltzmann constant.

Writing an energy balance at the surfaces:

$$\dot{q}_{s,i} = \dot{q}_{comb,s,i} + S_{s,i} + Wall.gain \qquad \text{Eq. 4-1.20}$$

$$\dot{q}_{s,o} = \dot{q}_{comb,s,o} + S_{s,o} \qquad \text{Eq. 4-1.21}$$

For internal surfaces $S_{s,i}$ can include both solar radiative and long-wave radiation generated form internal objects such as people or furniture.

Wall gain (WG) is an user-defined energy flow to the inside wall or window surfaces. It describes solar gains changing during the day due to different sun positions or can be used as a simple way to model floor heating or a chilled ceiling system. For external surfaces, $S_{s,o}$ consists of solar radiation only.

- External walls.

If we combine equation 4-1.11 to Eq. 4-1.21 we can obtain the following equation which express the inside surface heat flux for an external wall as a function of the boundary air temperatures.

$$\dot{q}_{s,i} = B_s T_{a,s} - C_s T_{a,s} + D_s \qquad \text{Eq. 4-1.22}$$

were;

$$B_s = \frac{e_s \cdot h_{s,o}}{(1 - f_s)}; \qquad \text{Eq. 4-1.23}$$

$$C_s = \frac{f_s}{(f_s - 1)} \cdot \left(\frac{1}{\mathrm{R}_{equiv,i} \cdot A_{s,i}} \right); \qquad \text{Eq. 4-1.24}$$

$$D_s = \frac{f_s \cdot S_{s,i} + e_s \cdot (S_{s,o} - k_{s,o}) + K_{s,i}}{(1 - f_s)}; \qquad \text{Eq. 4-1.25}$$

$$e_s = \frac{b_s^o}{a_s^o - h_s^o}; \qquad \text{Eq. 4-1.26}$$

$$fs = (b_s^o e_s - c_s^o) \cdot R_{equiv,i} A_{s,i}; \qquad \text{Eq. 4-1.27}$$

To calculate *Ks,i* and *Ks,o* we use the transfer function equations:

$$Ks,i = \sum_{k=0}^{n_{b_s}} b_s T_{s,o}{}^k - \sum_{k=0}^{n_{c_s}} c_s T_{s,i}{}^k - \sum_{k=1}^{n_{d_s}} d_s \dot{q}_{s,i}{}^k \qquad \text{Eq. 4-1.28}$$

$$Ks,i = \sum_{k=0}^{n_{a_s}} a_s T_{s,o}{}^k - \sum_{k=0}^{n_{b_s}} b_s T_{s,i}{}^k - \sum_{k=1}^{n_{d_s}} d_s \dot{q}_{s,o}{}^k \qquad \text{Eq. 4-1.29}$$

- Walls with boundary conditions.

Equation 4-1.22, can be also used to describe walls with boundary conditions with a known boundary temperature, $T_{b,s}$, with $T_{b,s}$ substituted for $T_{a,s}$.

- Adjacent, Internal walls and walls with identical boundary conditions.

For adjacent walls to another zone, internal walls and walls with identical boundary conditions, equation 4-1.22 can be used but with;

Adjacent zone:	$T_{a,s}=T_{star,j}$
Internal wall :	$T_{a,s}=T_{star,i}$
Walls with identical boundary conditions:	$T_{a,s}=T_{star,i}$

and

$$B_s = \frac{e_s}{(1-f_s)} \cdot \left(\frac{1}{\mathrm{R}_{equiv,j}\, A_{s,j}} \right); \qquad \text{Eq. 4-1.30}$$

$$e_s = \frac{b_s^o}{a_s^o + \dfrac{1}{R_{equiv,j} A_{s,j}}} \qquad \text{Eq. 4-1.31}$$

If it is an internal wall TRNSYS considers both sides of the wall, so the area of the wall is doubled.

It is possible to specify a boundary condition for an external surface temperature instead of with the air temperature by setting HBACK≤0.001. In this case equation 4-1.22 is applied with:

$T_{a,s}=T_{s,o}=T_{b,s.}$

$$B_s = \frac{b_s^o}{1 + c_s^o R_{equiv,i} A_{s,i}}; \qquad \text{Eq. 4-1.32}$$

$$C_s = \frac{c_s^o}{1 + c_s^o R_{equiv,i} A_{s,i}};$$ Eq. 4-1.33

$$D_s = \frac{K_{s,i} + c_s^o R_{equiv,i} A_{s,i} S_{s,i}}{1 + c_s^o R_{equiv,i} A_{s,i}};$$ Eq. 4-1.34

Once defined all these variables, equation 4.1.8 can be used in order to calculate all the gains to a zone from all the surfaces. Then, the main heat balance, equation 4-1.1, can be applied to calculate the total gains to a zone *Qi*.

For now on, the procedure used by TRNSYS to calculate heating and cooling requirements is explained:

4.1.2. Heating and cooling in TRNSYS.

4.1.2.1 Floating zone temperature (No heating or cooling).

The change of internal energy inside a free floating temperature zone can be expressed as:

$$C_i \frac{d}{dt} T_i = \dot{Q}_i$$ Eq. 4-1.35

Where *Ci* is the thermal capacitance of the zone i.

The heat gain, $\dot{Q}$, is considered constant during any time step, evaluated at average values of the zone temperatures. The solution to the differential equation for final temperature for a given time interval is:

$$T_{i,\tau} = T_{i,\tau-\Delta t} + \frac{\overline{\dot{Q}_{i\Delta t}}}{C_i}$$ Eq. 4-1.36

Where:

Δt	is the simulation time-step.
$T_{i,\tau-\Delta t}$	is the zone temperature at the beginning of the time-step.

Temperature variation is linear, such that average is:

$$\overline{T}_i = \frac{T_{i,\tau} + T_{i,\tau-\Delta t}}{2} \qquad \text{Eq. 4-1.37}$$

If equation 4-1.37 is solved for $T_{i,\tau}$ and the result substituted into equation 4-1.36, along with the individual expressions representing the net heat gain, the following equation is obtained:

$$\frac{2 \cdot C_i \cdot (\overline{T}_i - T_{i,\tau-\Delta t})}{\Delta t} = \sum_{j=1}^{\substack{adjac.surfaces \\ zones.i.to.j}} \sum \dot{m}_{cplg,s} \cdot C_p \cdot \overline{T}_j + \mathrm{m}_{inf,i} \cdot C_p \cdot T_a + \sum^{\substack{known \\ boundaries}} \dot{m}_{cplg,i} \cdot C_p \cdot T_{b,s}$$
$$-\left(\frac{1}{R_{star,i}} + \left(\sum^{\substack{known \\ boundaries}} \dot{m}_{cplg,i} + \sum_{j=1}^{\substack{adjac.surfaces \\ zones.i.to.j}} \sum \dot{m}_{cplg,s} + \dot{m}_{inf,i} + \sum_{k}^{nvent} \dot{m}_{v,k,i} \right) Cp \right) \overline{T}i$$
$$+\left(\frac{1}{R_{star,i}} \cdot \overline{T}_{star,i} + \sum_{k}^{nvent} \dot{m}_{v,k,i} \cdot C_p \cdot T_{v,k} + Q_{g,c,i} \right)$$

Equation 4-1.38

Equations 4-1.8 and 4-1.13 can be equated and regrouped to obtain:

$$\left(\frac{1}{R_{star,i}} - \sum^{\mathrm{int}.walls} A_s B_s + \sum^{Surf.ini} A_s C_c \right) \overline{T}_{star,i} - \left(\sum^{adj.zone.walls.i.to.j} \sum A_s B_s \right) \cdot T_{star,j} - \frac{1}{R_{star,i}} \cdot \overline{T}_i$$
$$= \left(\sum^{\substack{exterior \\ surfaces}} A_s B_s \right) \cdot T_a + \sum^{\substack{known \\ boundaries}} A_s B_s T_{b,s} + \sum^{\substack{surface \\ in.zone.i}} A_s \cdot (D_s + S_{s,i})$$

Equation 4-1.39

The set of the two energy balances obtained given by equations 4-1.38 and 4-1.49, written for all zones, results in a linear set of equations in average zone temperatures and average star temperatures. In matrix form:

$$[X]\left[\overline{T}\right] = [Z]; \qquad \text{Eq. 4-1.40}$$

This matrix can be written as:

$$[X]=\begin{bmatrix} X_{11}X_{12} \\ X_{21}X_{22} \end{bmatrix};$$ Eq.4-1.41

$$[\overline{T}]=\begin{bmatrix} \overline{T}_1 \\ \overline{T}_2 \end{bmatrix}=\begin{bmatrix} \overline{T} \\ \overline{T}_{star} \end{bmatrix};$$ Eq. 4-1.42

$$[Z]=\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix};$$ Eq. 4-1.43

Where:

$$X_{11,ii}=\left(\sum^{\substack{surfaces\\ i.to.j}} \dot{m}_{cplg,s}+\dot{m}_{inf,i}+\sum_{k}^{nvent}\dot{m}_{v,k,i}\right)\cdot C_p+\frac{2C_i}{\Delta t}+\frac{1}{R_{star,i}}+\sum^{\substack{known\\ boundaries}} m_{cplg,i}\cdot C_p\ ;$$

Equation 4-1.44

$$X_{11,jj}=\sum_{j=1}^{\substack{adjac.surfaces\\ zones.i.to.j}}\sum m_{cplg,s}\cdot C_p\ ; for\ \_i\neq j\ ;$$ Eq. 4-1.45

$$X_{21,ii}=-\frac{1}{R_{star,i}}\ ;$$ Eq. 4-1.46

$$X_{21,jj}=0\ ;$$

$$X_{22,ii}=-\sum^{\text{int}.walls} A_s\cdot B_s+\sum^{\substack{surf.in\\ zone.i}} A_s\cdot C_s+\frac{1}{R_{star,i}}\ ;$$ Eq. 4-1.47

$$X_{22,ij}=-\sum^{\substack{adj.walls\\ zones.i.to.j}}\sum A_s B_s\ ;$$ Eq. 4-1.48

$$Z_{1,i}=\dot{m}_{inf,i}\cdot C_p\cdot T_a+\sum^{\substack{known\\ boundaries}}\dot{m}_{cplg,s}\cdot C_p\cdot T_{b,s}+\sum_{k}^{n.vent}\dot{m}_{v,k,i}\cdot C_p\cdot T_{v,k}+\frac{2C_i\cdot T_{i,\tau-\Delta t}}{\Delta t}+Q_{g,c,i}\ ;$$

Equation 4-1.49

$$Z_{2,i}=\left(\sum^{ext.surf.} A_s B_s\right)\cdot T_a+\sum^{\substack{known\\ boundaries}} A_s B_s T_{b,s}+\sum^{\substack{surf\\ in.zone.i}} A_s\left(D_s+S_{s,i}\right);$$ Eq. 4-1.50

If all the zones are in floating temperature;

$$\left[\overline{T}\right] = [X]^{-1}[Z] \qquad \text{Eq. 4-1.51}$$

The final temperature for each zone *i* is:

$$T_{i,\tau} = 2\overline{T}_i - T_{i,\tau-\Delta t} \qquad \text{Eq. 4-1.52}$$

4.1.2.2 Simplified heating and cooling.

It is possible to determine energy requirement of each zone in an idealized way. Heating and cooling requirements are a function of the zone temperature as the figure 4-1.6 describes:

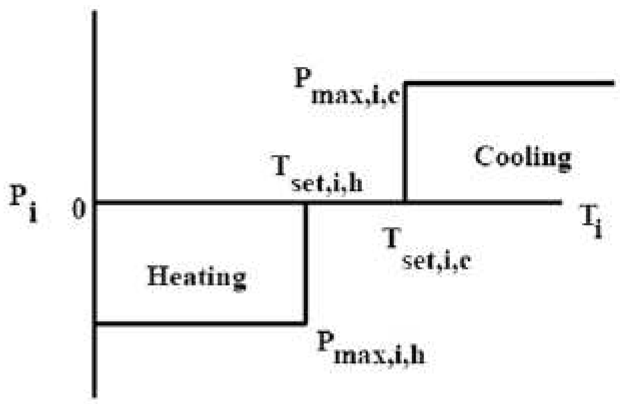


Figure 4-1.6. Power output Vs. temperature.

Were:

P_i; is the output power for the zone *i*.

$P_{max,i}$; is the maximum power for the zone *i*

$T_{set,i}$; is the set temperatures for heating or cooling for the zone *i*.

On the vertical axis is represented the power of the heating-cooling system, on the horizontal axis is represented the temperature of the zone. As we see, when the temperature of the zone is between the preset range (free floating temperature) heating or cooling power required is zero. If the temperature of a free floating zone is within the heating or cooling regions at the end of a timestep,

power is applied throughout the timestep so that the final zone temperature just reaches *Tset*. If the power required is greater than the maximum specified, then the maximum power is applied throughout the timestep and the zone temperature is again free floating.
For the simulation of heating systems that produce a partially radiative gain, a radiative fraction can be defined on TRNSYS. This fraction of the power is supplied as internal radiative gains and distributed to the walls of the zone.

The temperature change of the zone air, when power is supplied, is assumed to be linear. If power is required and enough is available to maintain the final zone temperature at *Tset,i*, then the final and average zone temperatures are known.

$$T_t = T_{set,i};$$ Eq. 4-1.53

$$T_{req,i} = \frac{T_{\tau-\Delta t} + T_{set,i}}{2};$$ Eq. 4-1.54

Were;

$T_{req,i}$ is the average zone temperature over the time-step if less than maximum power is required.

Considering the case of zones that are in different control regions, i.e., zones which have different preset temperatures. For those zones with floating temperatures, the solution for average zone temperatures and star temperatures is of the form:

$$\left[\overline{T}\right] = [X']^{-1}[Z'];$$ Eq. 4-1. 55

Coefficients of matrix X' and vector Z' depend on the control region, when temperatures are under the range required (comfort region), with no energy requirement:

$$X'_{ij} = X_{ij};$$ for all *i* and *j*. Eq. 4-1.56.

$$Z'_i = Z_i$$ Eq. 4-1.57.

For zones which temperature falls below the point for maximum heating or above that for maximum cooling:

$$X'_{ij} = X_{ij};$$ for all *i* and *j*. Eq. 4-1.58.

$$Z'_i = Z_i + P_{\max.i,h}; or; Z'_i = Z_i - P_{\max,i,c}$$ Eq. 4-1.59.

For zones that fall within the heating or cooling regions and require less than maximum power, the final temperature is assumed to be equal to the heating or cooling set temperature and the average room temperature is then *Treq,i*. The equation 4-1.35 can be rewritten to include the power requirements obtaining:

$$C_i \frac{d}{dt} T_i = \dot{Q}_i - P_i$$ Eq. 4-1.60.

P_i and $\dot{Q}_i$ are considered constant over the time-step and $\dot{Q}_i$ is evaluated at the average zone temperature. Substituting into equation 4-1.60:

$$\begin{aligned}
&P_i - \frac{1}{R_{star,i}} \cdot \overline{T}_{star,i} - \sum_{j=1}^{\substack{adjac.surfaces\\ zones.i.to.j}} \sum \dot{m}_{cplg} C_p \overline{T}_j = \\
&-\left[\frac{1}{R_{star,i}} + \left(\dot{m}_{\inf,i} + \sum_{j=1}^{\substack{adjac.surfaces\\ zones.i.to.j}} \sum \dot{m}_{cplg} + \sum^{\substack{known\\ boundaries}} \dot{m}_{cplg} \right) C_p \right] \overline{T}_{req,i} \\
&-\frac{C_i}{\Delta t}(T_{set,i} - T_{\tau-\Delta t}) + \dot{m}_{inf,i} \cdot C_p \cdot T_a + \sum_k^{nvent} \dot{m}_{v,k,i} \cdot C_p \cdot T_{v,k} + Q_{g,c,i} + \sum^{\substack{known\\ boundaries}} \dot{m}_{cplg,s} C_p T_{b,s}
\end{aligned}$$

Equation 4-1.61

Equation 4-1.61 must be substituted into the equation set of energy balances on all zones which are in the less than maximum heating or cooling region. The solution given by equation 4-1. 55 is valid but with the following substitutions for zones evaluated with equation 4-1.61.

$X'_{11,jj} = X_{11,ij}; for\_i \neq j;$ Eq. 4-1.62

$X'_{11,ii} = 1.0;$ Eq. 4-1.63

$X'_{12,ij} = X_{12,ij};$ Eq. 4-1.64

$X'_{22,ii} = X_{22,ii};$ Eq. 4-1.65

$X'_{21,ii} = 0$ Eq. 4-1.66

$$Z'_i = Z'_i - Z'_{im} T_{req,m} \qquad \text{Eq. 4-1.67}$$

In a first approximation, TRNSYS calculates the temperatures of each zone in the case of no heating or cooling. Then, for zones were heating or cooling is required, the energy to maintain the final zone temperature at the set temperature is determined. Then, if the required energy is less than the maximum power available, TRNSYS considers that the zone is within the less than the maximum heating or cooling region. Otherwise heating or cooling power required is equal to the maximum. The set of equations represented by the matrix eq. 4-1.55 is solved. The process is repeated until the control does not change. Then, energy requirements are evaluated for the zones set at setpoints.

4.2 Procedure followed:

The first thing that should be noticed when using TRNSYS, is that this software has two different programs used to calculate the thermal behaviour of a certain building. The first one, SIMULATION STUDIO, is a platform in which the simulation is carried out. It is the main visual interface of TRNSYS which create projects by drag-and-dropping components to the workspace, connecting them together and setting the global simulation parameters.

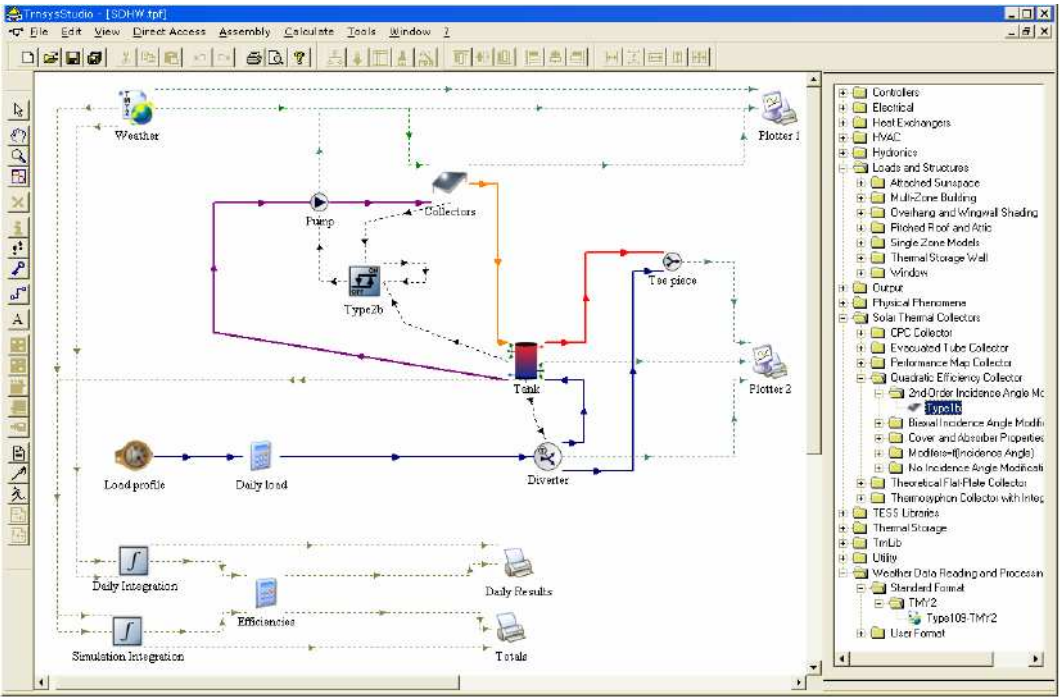


Figure 4-2.1. The Simulation Studio.

The second one is a specific component called TRNBuild or TYPE 56, designed to model the thermal behavior of a building divided into different thermal zones. It permits create, delete and edit building properties like the insulation of walls, optical properties of building envelope, windows shadings, windows thermal properties, heating and cooling systems, etc.

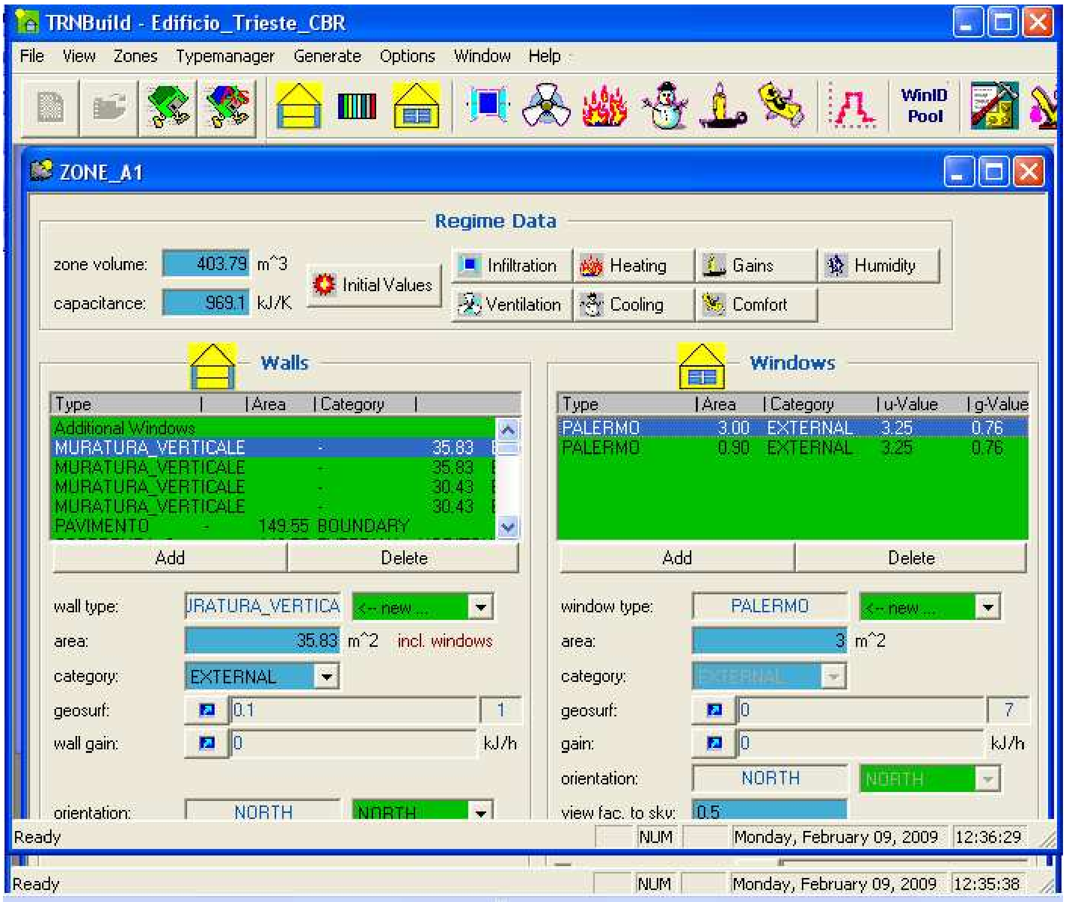


Figure 4-2.2. TRNBuild main visual interface.

4.2.1 Using Simulation Studio.

In order to create a new building simulation, first thing to do is to create a new multizone building project. To do this, is necessary to launch the *building wizard* on Simulation Studio. This can be done by choosing on Simulation Studio; *File/New*, selecting *"Building Project (Multizone)"* and then clicking on *next*. The following figure illustrates how to do this:

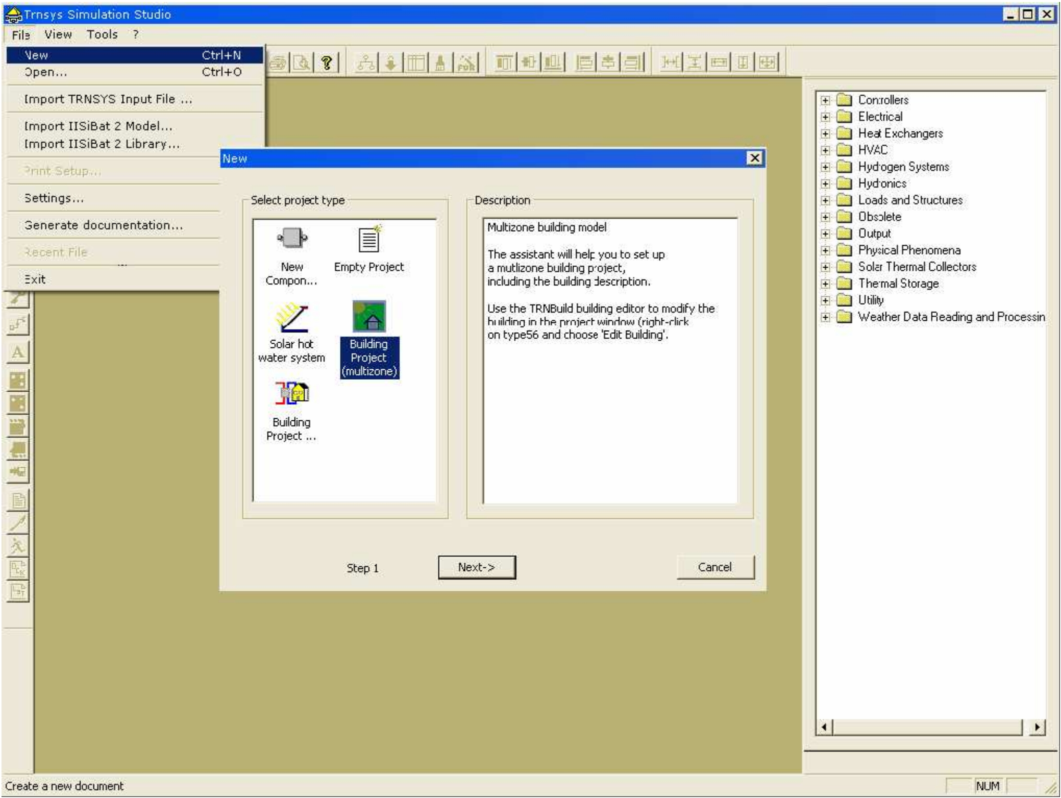


Figure 4-2.3. How to launch the multizone building wizard (Step 1).

The first step necessary, is to define the thermal zones of our building. If we choose to create more than one thermal zone, we will need to define which zones are adjacent to which others. This is done using a grid layout, (figure 4-2.4). Clicking in a cell of the grid, the wizard will create a zone at that location. Here, we should explain that a thermal zone is not the same as a room of a building, the definition of a thermal zone must fulfil other requirements like the temperature difference between zones, the heating equipments existing in the building and characteristics of the building envelope. This definition may vary depending on the laws or regulations which are being applied.

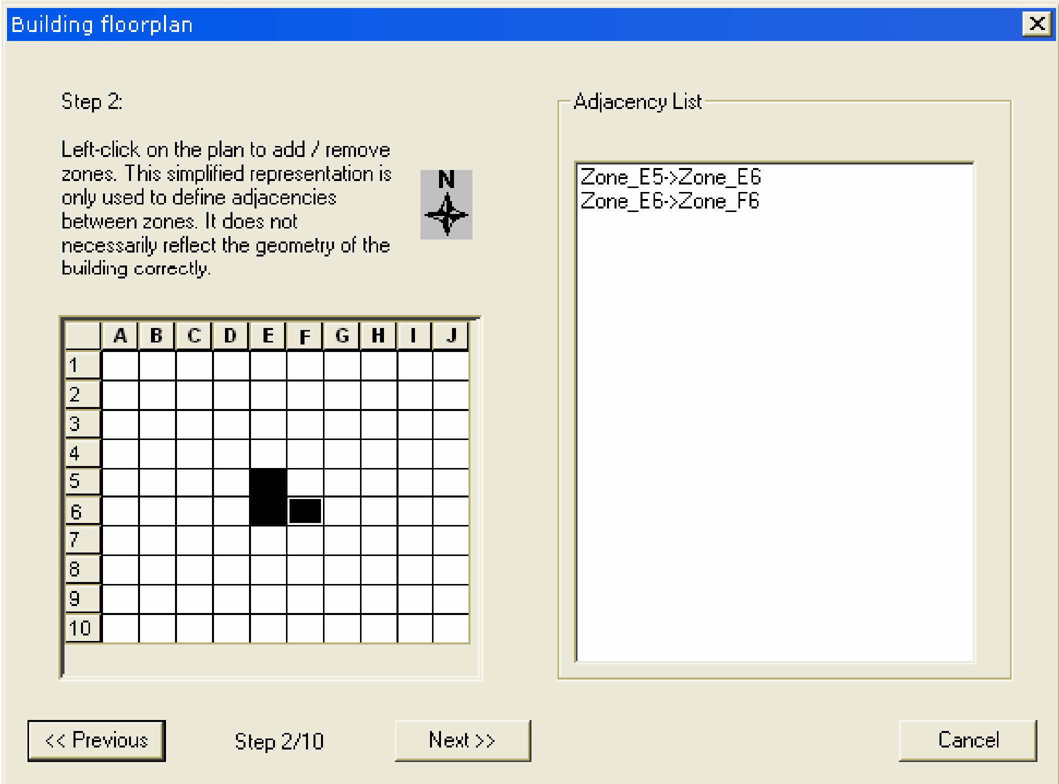


Figure 4-2.4. Selecting thermal zones (Step 2).

Next, TRNSYS will ask us the dimensions of the thermal zones defined previously. Selecting by clicking with the mouse on the thermal zone created, we will be able rename it and define its dimensions (figure 4-2.5).

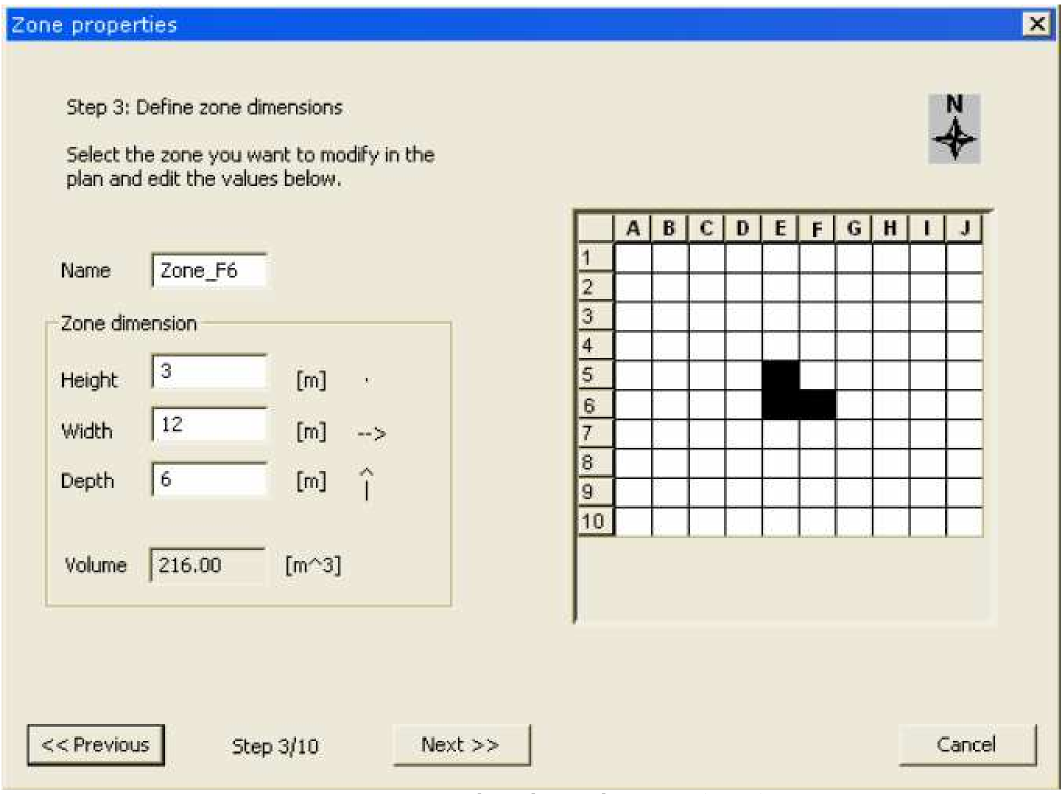


Figure 4-2.5. Setting thermal zones dimensions (Step 3).

Clicking on *next*, then, a window will pop-up in which $\left(\dfrac{windows}{external\_walls}\right)$ surface ratio can be introduced, as well as the orientation of the building.

Here, we will be able to specify the location of the building, as well. This is detailed in the next figure (4-2.6):

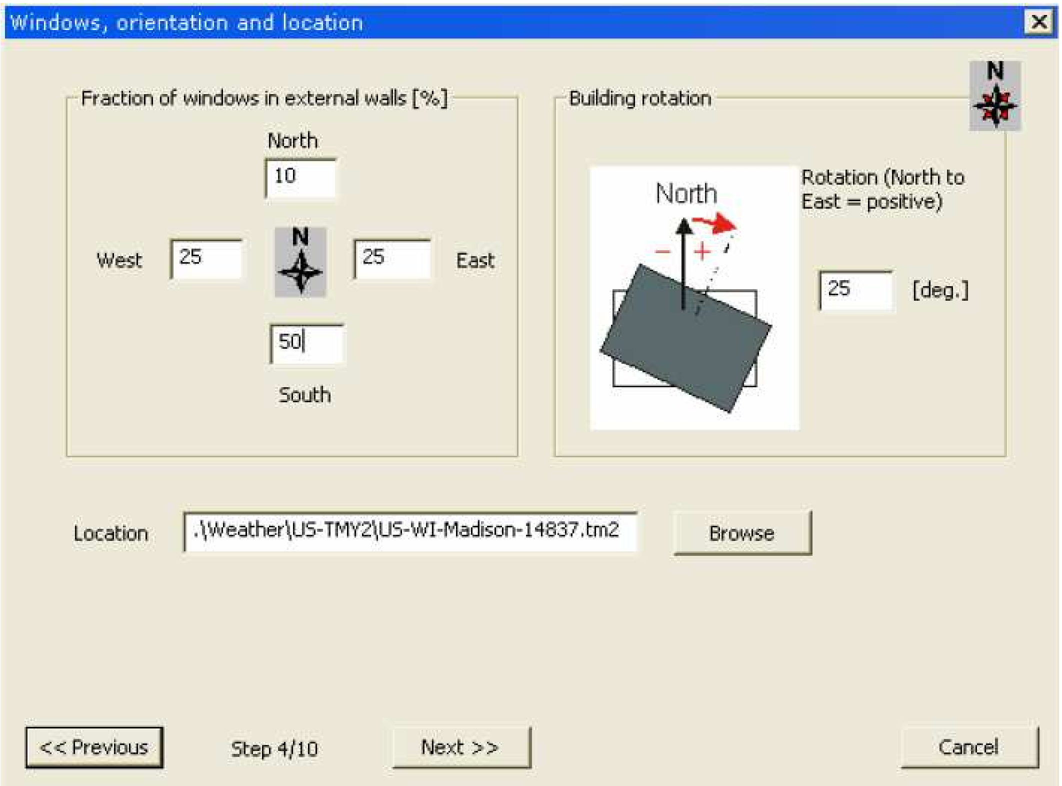


Figure 4-2.6. Fraction of windows in external walls and building orientation (Step 4).

Clicking on *next*, further characteristics of the building can be introduced. In the next collection of pictures, we show the procedure to do this.

Is important to remark that all these characteristics can be modified later with **TRNBuild**.

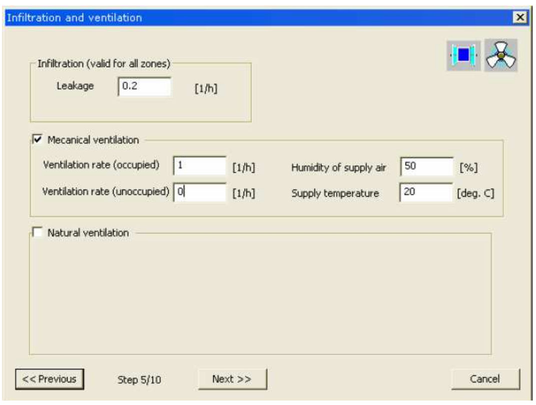


Figure 4-2.7. Step 5. Infiltration and Ventilation.

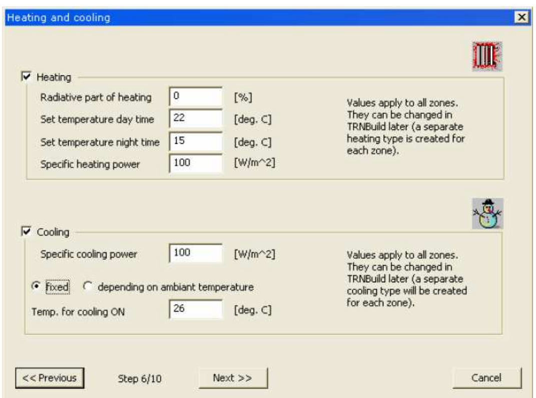


Figure 4-2.8. Step 6. Defining cooling and Heating

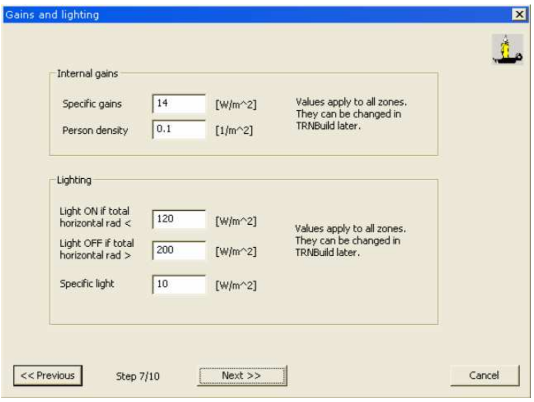


Figure 4-2.9. Step 7. Adding internal gains and lighting

→

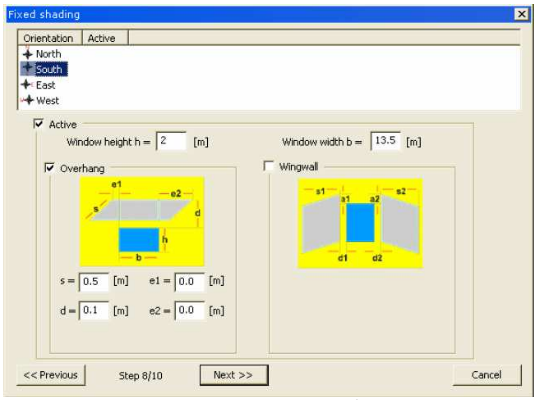


Figure 4-2.10. Step 8. Adding fixed shading.

We should notice, that internal gains are activated by default values. If we want to add a different internal gain first, we should remove default values in TRNBuild and then, add the new value of the internal gain wanted.

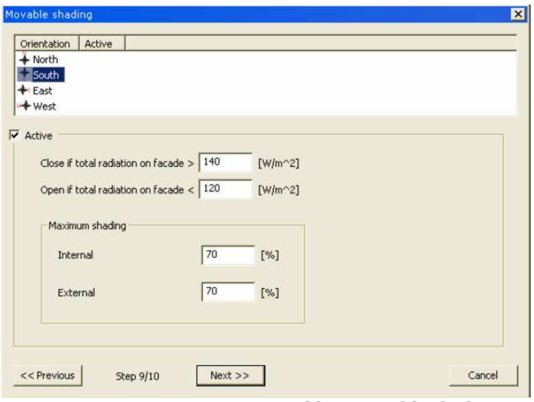


Figure 4-2.11. Step 9. Adding movable shading.

→

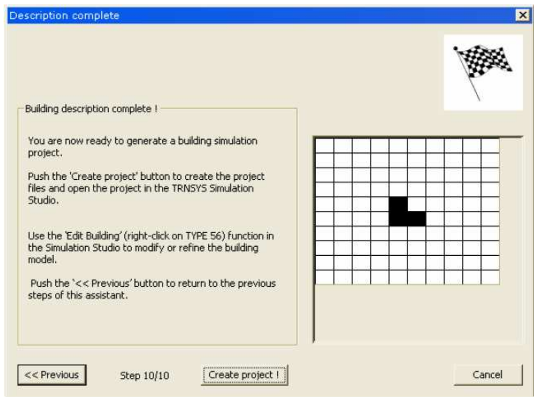


Figure 4-2.12. Step 10. Finishing the building wizard

Once having specified all the properties, clicking on create project, TRNSYS will generate a Simulation Studio file and a TRNBuild file (a building file) which we will change afterwards.

Depending on the properties defined with *the building wizard*, the visual layout in Simulation Studio may vary:

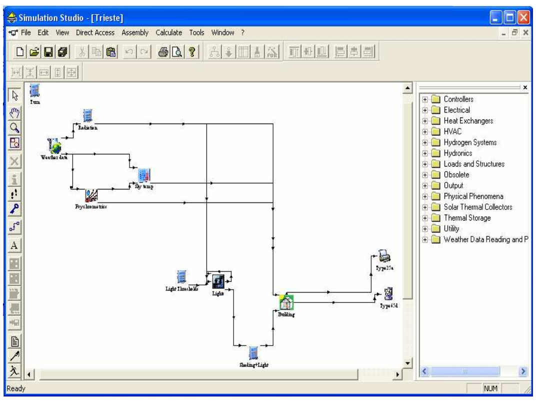


Figure 4-2.13.

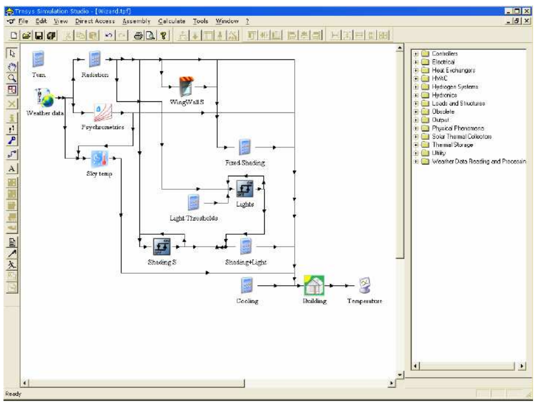


Figure 4-2.14.

Figures 4-2.13 and 4-2.14 show two possible layouts on Simulation Studio created with the building wizard. Figure 4-2.13 shows the typical configuration used during this project, figure 4-2.14 shows a more complex configuration since, in this project shadings have not been considered and cooling and heating properties have been introduced on TRNBuild.

Once created the Simulation Studio file, we can modify the configuration:

We can change the climatic location that it is being simulated by double-clicking with the left button of the mouse on *Weather Data*, then, going to *external files* and then to *Brows*. Here, depending on were our computer has the TRNSYS weather files, we should go to *Programs→TRNSYS 16→Weather→Meteonorm→Choose the Continent→Choose the Country and the City* and then left click on open.

Picture 4-2.15 details this process:

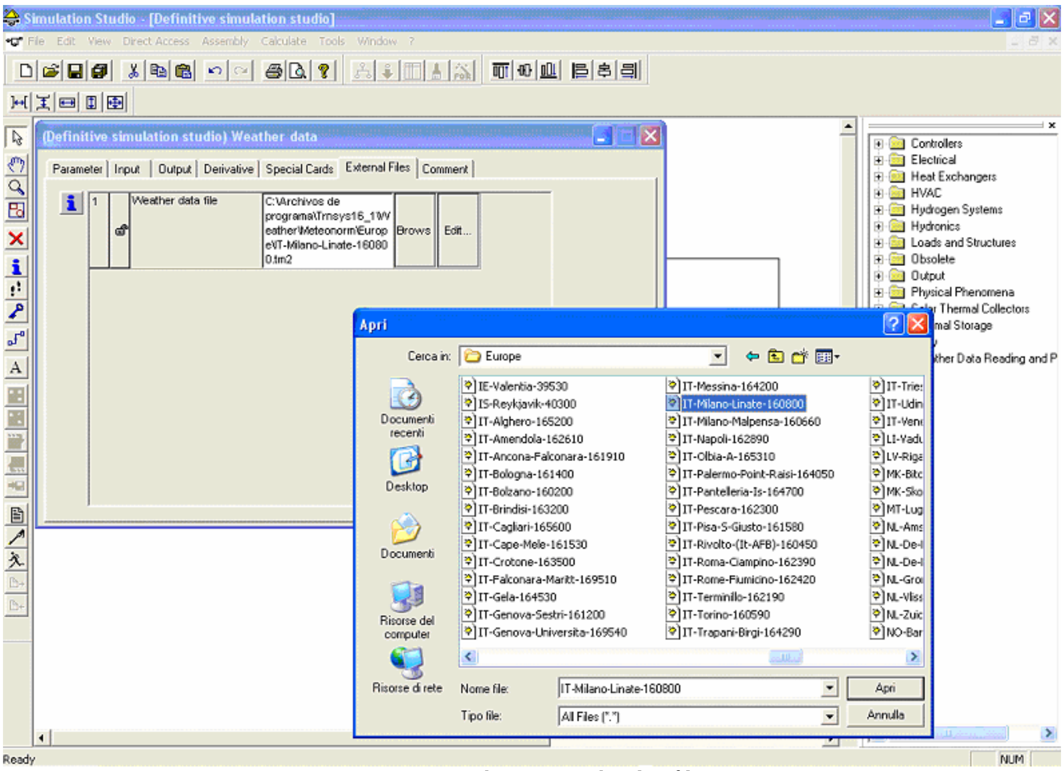


Figure 4-2.15.Changing weather data files.

We can change the connections between components in Simulation Studio by double-left-clicking on the connection wanted, then, a window will pop-up with the default connections. Here, is were we can modify them.

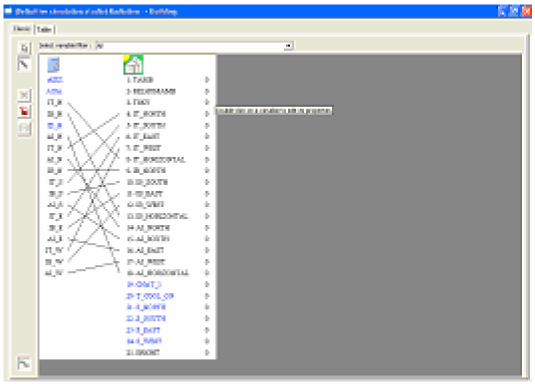


Figure 4-2.16. Modifying connections between components.

An important component of Simulation Studio is the Online plotter, which outputs useful information about the simulation when it is being run. It displays a graphical output during the simulation which can include several physical variables. During this project it has been used to display the temperature variation throughout the whole year. The window with the online plotter, (figure 4-2.18), will automatically pop-up when the simulation is started by pressing F8.

We can change the properties of the online plotter such as the variables displayed, variables names and axis limits by double-clicking on its icon and changing parameters (figure 4-2.17).

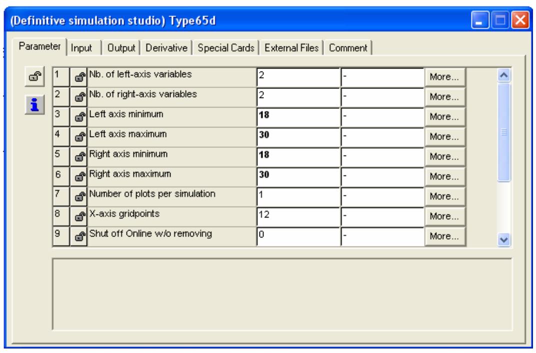


Figure 4-2.17. Changing Online plotter properties.

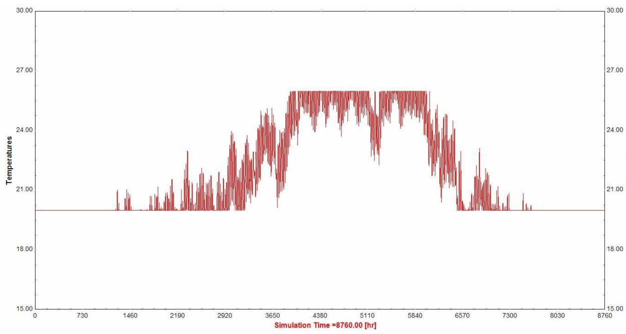


Figure 4-2.18. A typical temperature output on online plotter

A double-left-click on the connection between the Online plotter and the building icons will pop-up a window in which we can change the variables appearing on the Online plotter (figure 4-2.19).

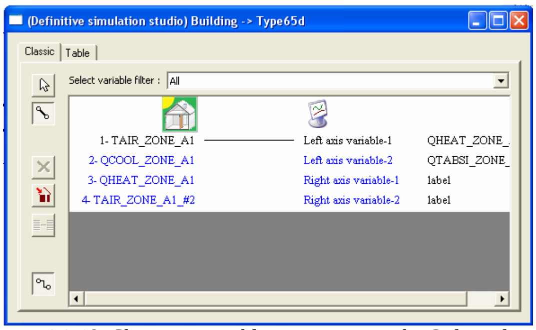


Figure 4-2.19. Changing variables appearing on the Online plotter.

Till this point, we have explained all the necessary variations in the Simulation Studio. From now on, we will explain the procedure to add, create and edit the building's properties required:

First, we should check the name of the building. This can be done by double-clicking on the building icon (), then, go to → *External files* → *Brows*. Here, we will check the name of the building created, TRNSYS gives a default name such as *BuildingProject.bui*, this name can be changed afterwards in TRNBuild.

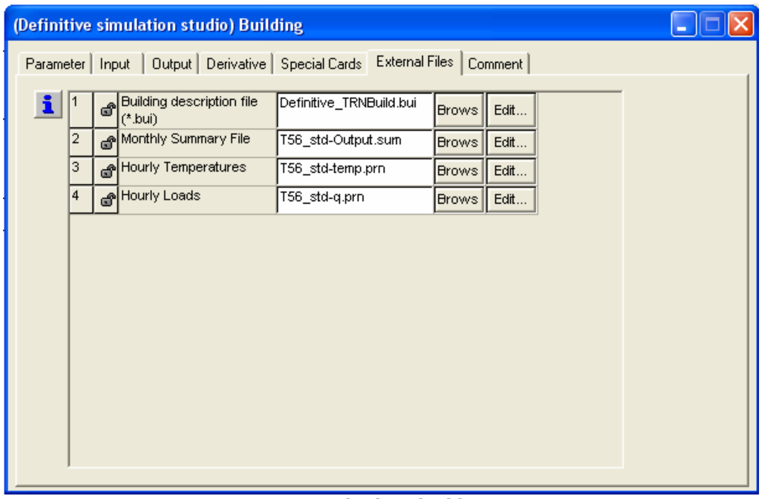


Figure 4-2.20. Checking building's name

Once done this, we will edit building properties. To do this, right click on the icon of the building and then go to *Edit building*. This will launch the TRNBuild (figure 4-2.21).

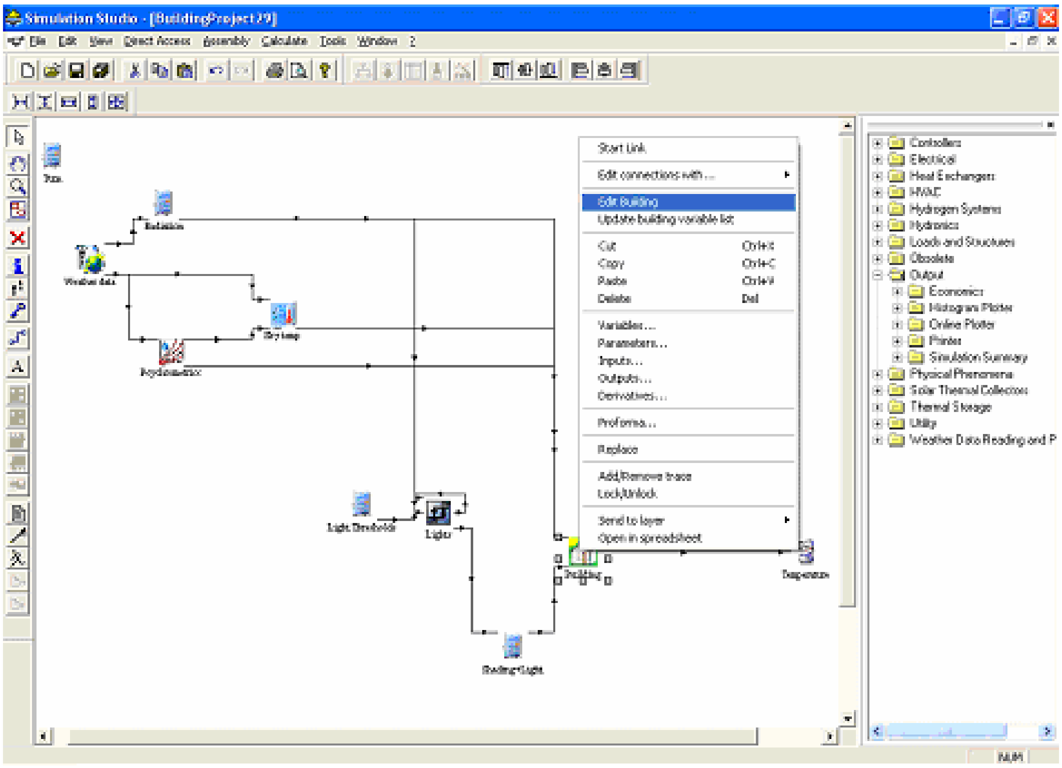


Figure 4-2.21. Launching TRNBuild.

4.2.2 Using TRNBuild.

Once launched TRNBuild we can start by defining the properties of the building envelope, i.e. walls, floor, roof, windows, etc.

In order to explain how TRNBuild was used, we will detail how the building described in the “report on the software for the valuation of energy performance of buildings” was defined on this software.

First, we will start by defining the layers within the structures of the building envelope. The walls of the building detailed in the report of the chapter 3 are multilayer walls, i.e., these walls are made of different layers with different thermal properties.

We can start defining the layers of the vertical walls. As we saw in chapter 3, vertical walls consist of five layers.

Layer name (From inside to outside)	Conductivity. (kJ/hmK)	Density (kg/m^3)	Specific heat (kJ/kgK)	Type
Internal plaster	3,24	1800	0,84	Massive
Brick wall 2	1,229	1000	0,84	Massive
Fibreglass	0,1404	80	1,03	Massive
Brick wall	0,936	600	0,84	Massive
External plaster	3,24	1800	0,84	Massive

Chart 4-2.1. Characteristics of vertical walls layers.

To introduce these properties for each layer is necessary to go to *The layer type manager* by clicking on the icon , then, a window will appear. Here, we can create a new layer by clicking on the icon N (new), then, we must specify a name for the new layer (for instance "Internal plaster") and define its properties and type on TRNBuild (conductivity, density, specific heat and type).

Figure 4-2.22, illustrates this proceeding:

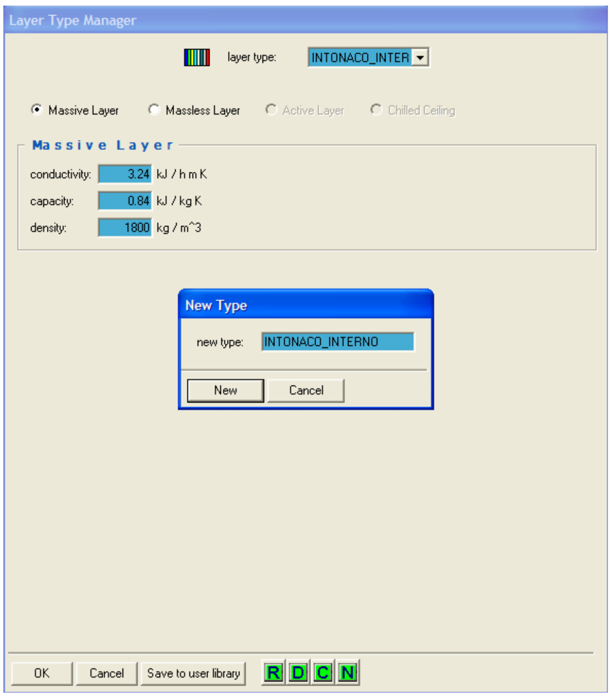


Figure 4-2.22. Creating a new layer.

We continue defining the roof of the test building as detailed in chapter 3. Following the procedure detailed above, the layers of the roof are created. The characteristics of roof layers are reported in the following chart.

Layer name (From inside to outside)	Conductivity. (kJ/hmK)	Density (kg/m^3)	Specific heat (kJ/kgK)	Type
Internal plaster	5,04	2000	0,84	Massive
Cement	2,52	1450	0,84	Massive
Expanded polyethylene	0,173	33	1,45	Massive
Concrete	3,348	1800	0,88	Massive
Tile	2,592	1800	0,84	Massive

Chart 4-2.2. Characteristics of roof layers.

Once done this, the last step remaining is to define the layers of the floor. The floor is made of four layers:

The characteristics of these layers are:

Layer name (From inside to outside)	Conductivity. (kJ/hmK)	Density (kg/m^3)	Specific heat (kJ/kgK)	Type
Tile	2,592	1800	0,84	Massive
Concrete	3,348	1800	0,88	Massive
Expanded polystyrene	0,1404	25	1,25	Massive
Cement	2,52	1450	0,84	Massive

Chart 4-2.3. Characteristics of floor layers.

Additionally, we have to define on TRNBuild the layers of which the internal walls are made of:

Layer name (From inside to outside)	Conductivity. (kJ/hmK)	Density (kg/m^3)	Specific heat (kJ/kgK)	Type
Plaster mortar	1,044	600	0,84	Massive
Holed brick	0,99	666	0,92	Massive
Plaster mortar	1,044	600	0,84	Massive

Chart 4-2.4. Characteristics internal walls layers.

Note: If we choose maseless layer –which does not consider the thermal inertia of the layer- we will have to enter the resistance of the layer only.

Once created all the necessary layers we can start defining all the structures of the building which are composed of these layers. To do this, we have to go to *the wall type manager* identified with the icon . Then, in the window which has just pop-up, we can create a new wall type by clicking on the icon  and entering the name of the new wall. We can start defining the vertical walls. So, the name of the new wall would be "Vertical walls". The different layers existing in the vertical walls are detailed in the next chart (4-2.5).

Number	Layer name (From inside to outside)	Thickness (m)	Type
1	Internal plaster	0,01	Massive
2	Brick wall 2	0,120	Massive
3	Fibreglass	0,120	Massive
4	Brick wall	0,120	Massive
5	External plaster	0,015	Massive

Chart 4-2.5. Vertical walls configuration.

The construction of the wall is specified by a series of layers starting from the "inside" surface (front) of the wall to the "outside" (back). To define a new wall, we have to select the layers created at the previous step with *The layer type manager* in the menu of layers (right box), and introduce them into the left box with the left arrow icon (add). Then, TRNBuild will ask us for the layer thickness. To remove a layer created press on the right arrow icon (del).

To define completely vertical walls characteristics, is necessary introduce in *The wall type manager* the layers and thicknesses as detailed on the chart 4-2.5. Once done this, the window on TRNBuild should look like the following figure:

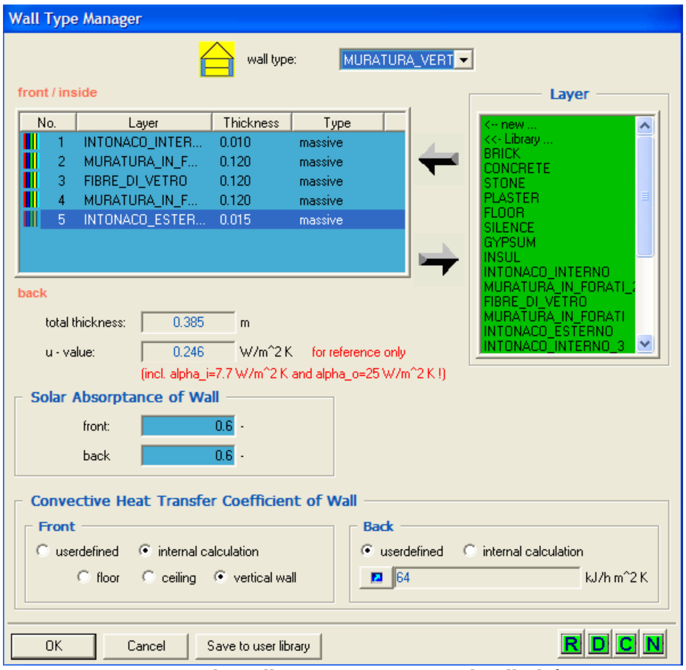


Figure 4-2.23. The wall type manager. Vertical walls definition.

Once added all the layers the wall will be finished, TRNBuild calculates the total thickness and the standard U-value of the wall automatically.

U-value obtained with TRNBuild: 0,246 W/m^{2}K

Note: Before go on, make sure that all the transmittances and thicknesses of the walls created are the wanted.

Is important to define here, the convective heat transfer coefficient of the walls, as well. TRNSYS manuals advice to define for the internal part of the walls, 11 kJ/hm^{2}K, or *internal calculation*, -here, depending on the wall type, we will be able to choose between; floor, ceiling or vertical wall- and for the external walls 64 kJ/hm^{2}K. In walls with boundary conditions, it is also possible to specify a boundary condition for the outside surface temperature rather than an air temperature by setting a convective heat transfer < 0.001.

Note: The standard U-value is determined with combined heat transfer coefficients of 7.7 W/(m²K) inside and 25 W/(m²K) outside.

In the vertical walls convective heat transfer coefficients were set to: Outside: 64 kJ/hm^{2}K.
Inside: Internal calculation.

Now, we will define the roof. The layer configuration of the roof is defined as reported in the following chart (4-2.6):

Number	Layer name (From inside to outside)	Thickness (m)	Type
1	Internal plaster	0,01	Massive
2	Cement	0	Massive
3	Expanded polyethylene	0,21	Massive
4	Concrete	0,05	Massive
5	Tile	0,01	Massive

Chart 4-2.6. Roof configuration.

On *The wall type manager* we will introduce the layer configuration as detailed on the chart 4-1.6. The window should look like figure 4-2.24.

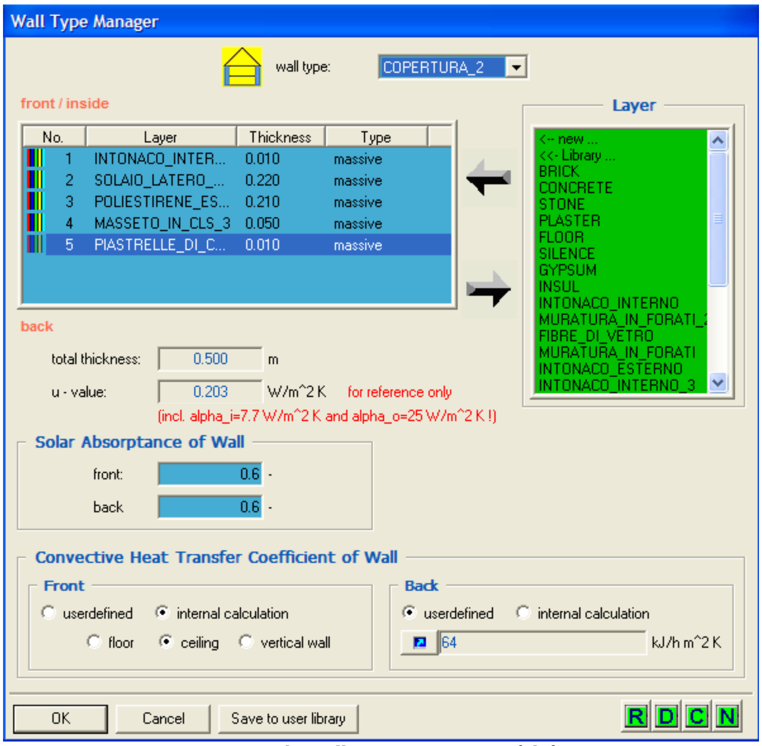


Figure 4-2.24. The wall type manager. Roof definition.

U-value obtained with TRNBuild: 0,203W/m^{2}K.

In the roof convective heat transfer coefficients were set to: Outside: 64 kJ/hm^{2}K.

Inside: Internal calculation.

The last part of the building thermal envelope is defined now, the floor. The layers included in the floor are reported in the following chart (4-2.7):

Number	Layer name (From inside to outside)	Thickness (m)	Type
1	Tile	0,01	Massive
2	Concrete	0,05	Massive
3	Extruded polystyrene	0,08	Massive
4	Cement	0,22	Massive

Chart 4-2.7. Floor configuration.

Introducing in *the wall type manager* the layers detailed on the chart 4-2.7 the window should look like figure 4-2.25.

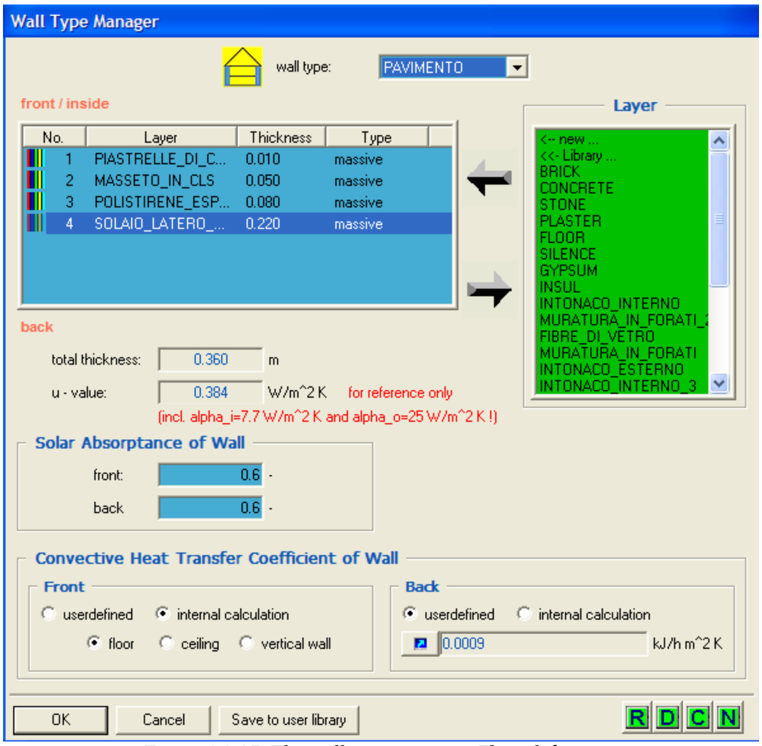


Figure 4-2.25. The wall type manager. Floor definition.

U-value obtained with TRNBuild: 0,384W/m^{2}K.

The floor convective heat transfer coefficients were set to: Outside: HBACK<0,001.

Inside: Internal calculation.

Finally, the internal walls are defined in *the wall type manager*, their configuration is detailed in the following chart (4-2.8)

Number	Layer name (From inside to outside)	Thickness (m)	Type
1	Plaster mortar	0,010	Massive
2	Holed brick	0,080	Massive
3	Plaster mortar	0,010	Massive

Chart 4-2.8. Internal walls configuration.

After introducing these layers, *the wall manager window* should look like the figure (fig.4-2.26).

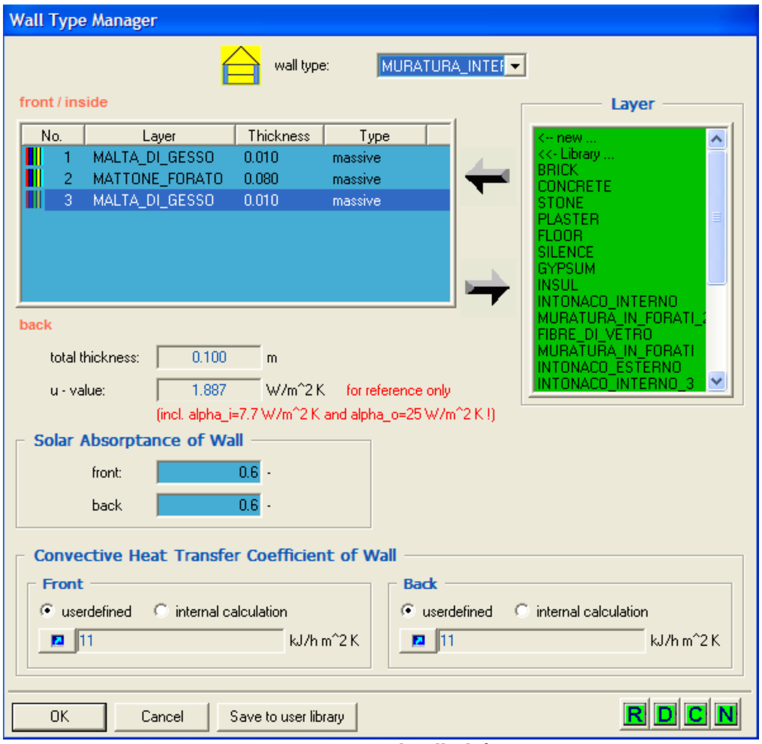


Figure 4-2.26. Internal walls definition.

U-value obtained with TRNBuild: 1,887 W/m^{2}K.

Now, all the walls of the building have been defined. The next step to be taken is to place this components on each thermal zone. Go to the TRNBuild *manager window*, and left click on the zone desired. Then, the window of the zone will pop-up *(the zone window)*.

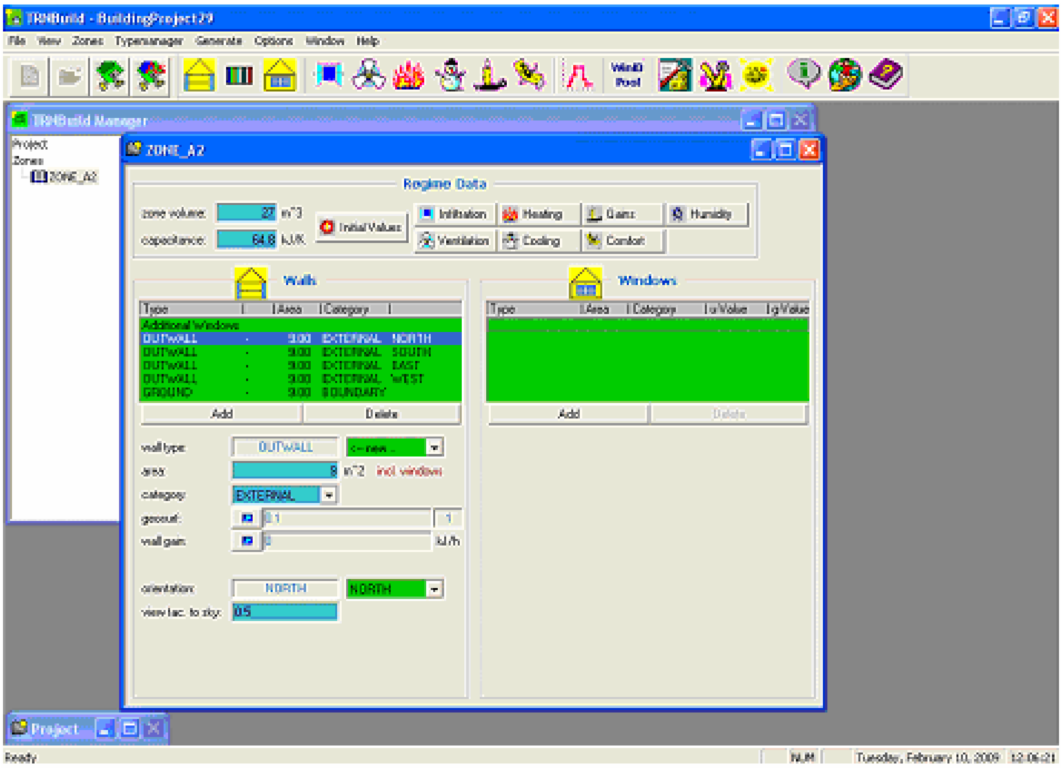


Figure 4-2.27. The zone window.

As we see in the *zone window*, TRNSYS has defined default characteristics for each wall. Some of them are right, others may be wrong so, is important to review all these values. Here, in the zone window, we will be able to introduce the orientation, area, wall type, category and boundary conditions of the walls, among of other characteristics such as the wall gains or geosurf. For each wall of the building envelope we have to define an orientation – clicking on the pull-down menu, we can select the orientation of each wall-, the wall type –selecting from the pull-down menu the walls created previously with *the wall type manager*- and the wall category –external, adjacent, internal or boundary-

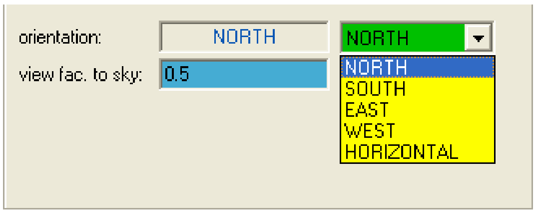


Figure 4-2.28. Specifying walls orientation.

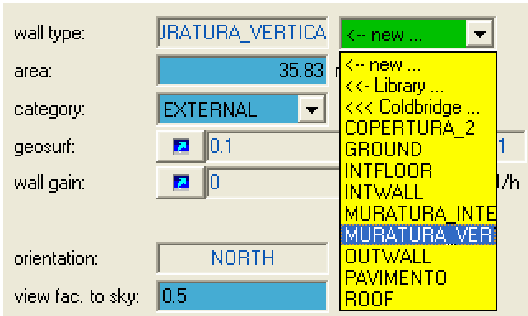


Figure. 4-2.29. Specifying wall type.

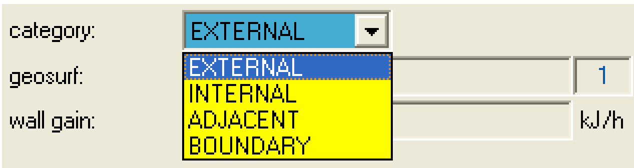


Figure. 4-2.30. Specifying wall category.

Other zone characteristics such as the wall gains or geosurf may be defined. Geosurf is the sum of the short wave radiation distribution factor, it cannot be greater than 1 in the whole zone.

There are certain walls, like the boundary walls, that require a special treatment. A wall with boundary category like the floor, requires a boundary condition, such as the boundary temperature which can be a constant value or schedule.

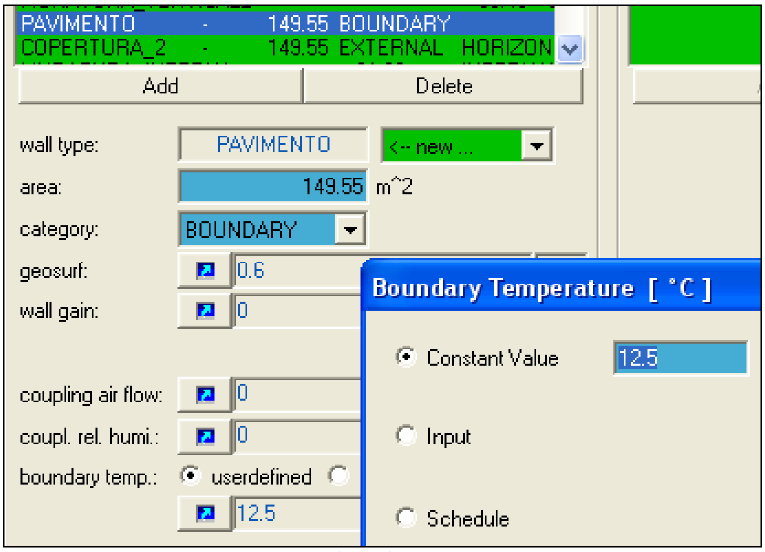


Figure. 4-2.31. Specifying floor boundary conditions.

Another fact that we should notice, is that the building generated by TRNSYS has no roof. So, we have to create one in TRNBuild. To do this, we have to click on *add* on the left box at the *zone window*, we specify the wall type (roof), the area of the roof (it equals to the area of the floor), the category (external) and the orientation (horizontal). Thus, the roof will be created.

Here, we detail a summary of the characterization of the walls used during the simulation:

Vertical walls: Orientations: North.
South.
East.
West.
Category: External.
Wall Type. Muratura_Verticale (Created with TRNBuild).

Floor: Orientation: Horizontal.
Category: Boundary. Temperature set at 12.5 ºC.
Wall Type: Pavimento (Created with TRNBuild).

Roof: Orientation: Horizontal.
Category: External.
Wall Type: Copertura_2 (Created with TRNBuild).

Internal walls: Orientation: none.

Category: Internal

Wall Type: Muratura_Interna (Created with TRNBuild).

Thermal bridges can be defined in TRNSYS, too. To create a linear thermal bridge is necessary to go to the *zone window* →*Click on add* →in *wall type* choose *coldbridge.*

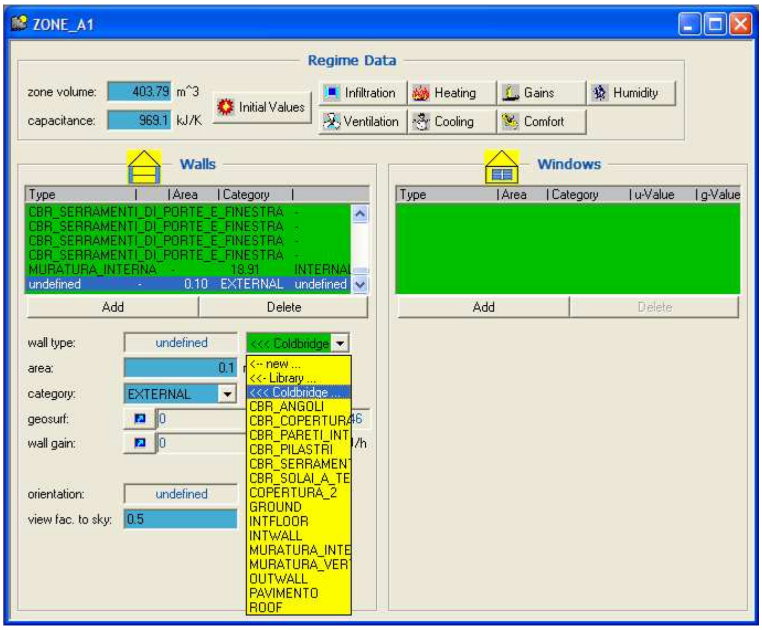


Figure. 4-2.32. Adding thermal bridges.

Then, a window in which we can specify properties of the thermal bridge such as resistance, solar absorptance, and convective heat transfer coefficient will pop-up.

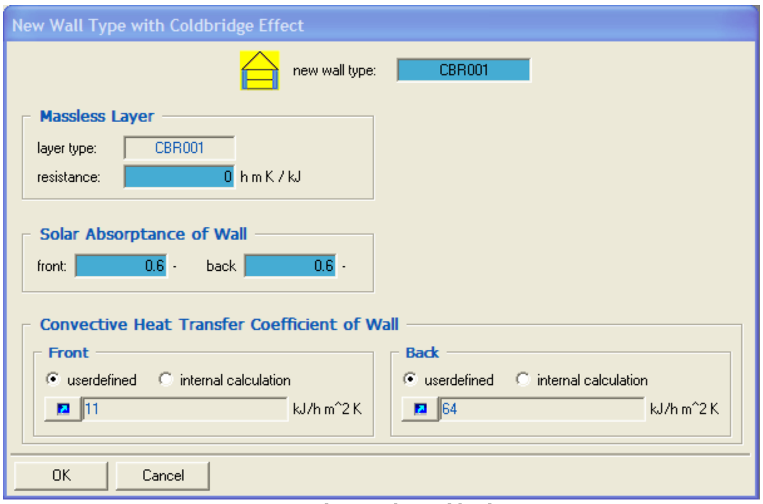


Figure. 4-2.33. Introducing thermal bridges properties.

Once introduced these properties, we have to go back to the *zone window* to specify the length, orientation and geosurf of the thermal bridge.

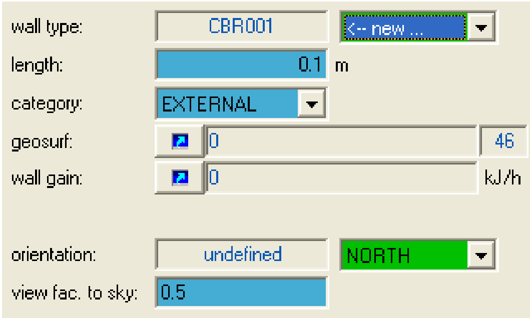


Figure. 4-2.34. Introducing length and orientation of the thermal bridge.

During the simulation, coldbridges properties introduced were;

Class of thermal bridge	Name	Resistance (hmK/kJ)	Thermal bridge length (m)
Roofs and floor.	CBR_COPERTURA CBR_SOLAI_A_TERRA	0,5	Roof: 48,92 Floor:48,92
Corners	CBR_ANGOLI	0,31	N=S=E=O: 2,70
Internal walls	CBR_PARETI_INTERNE	5,56	N: 6x2,70 S=O: 4x2,70 E: 2x2,70
Pillars	CBR_PILASTRI	0,23	N=S=E=O: 4x2,70
Window and door openings	CBR_SERRAMENTI_DI_ PORTE_E_FINESTRE	0,46	N: 7,40x2+4,20 S: 5,00+9,80 O=E: 7,40x2

Chart 4-2.9. Characteristics of linear thermal bridges.

The next thing to do to is to define the windows. To define window properties go to the *window type manager* which is identified by the icon , this will launch the next window:

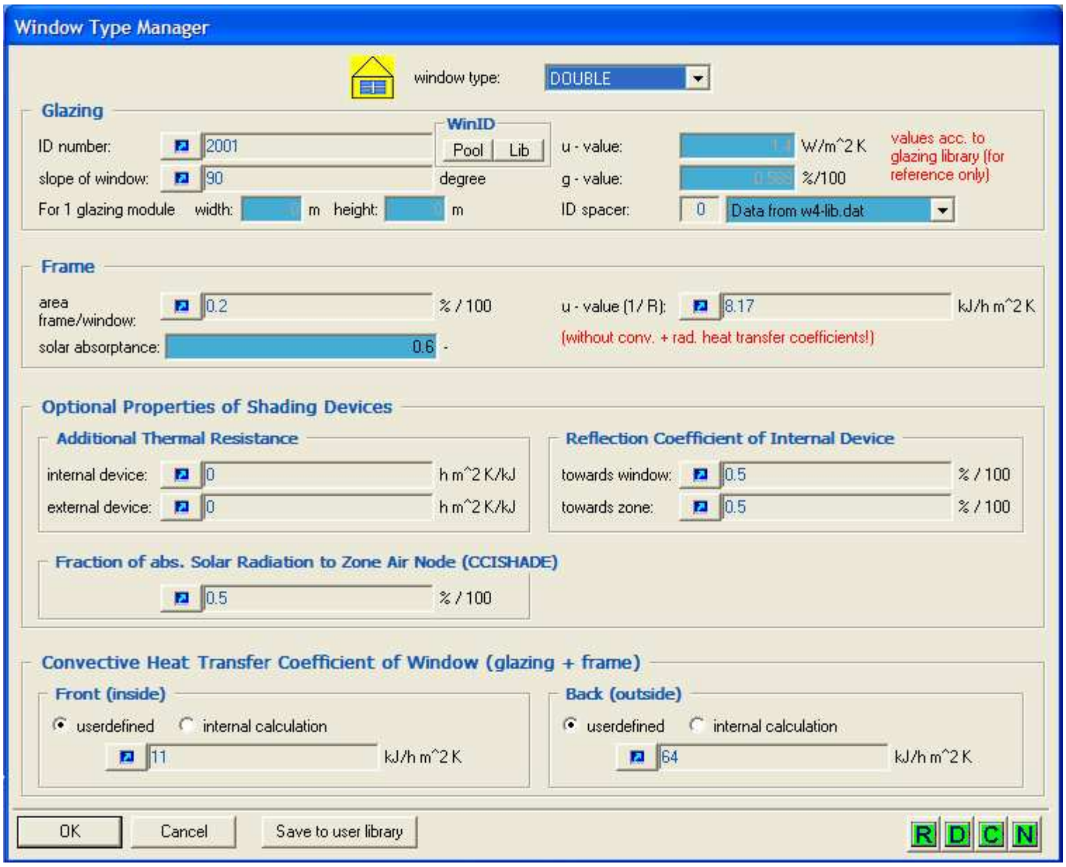
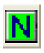


Figure. 4-2.35. The window type manager.

In this window we can introduce window properties such as the ratio frame/window area, frame transmittance, thermal and optical properties of the shading devices (when activated), glazing spacer and the convective heat transfer coefficient of the window. Other properties like transmittance and g-value of the glazing cannot be introduced manually, they have to be chosen from the window library.

So, the procedure to create a new window is to define the new window name by clicking on the icon 

and, choose the desired glazing from windows library by clicking on 

which launch the library window.

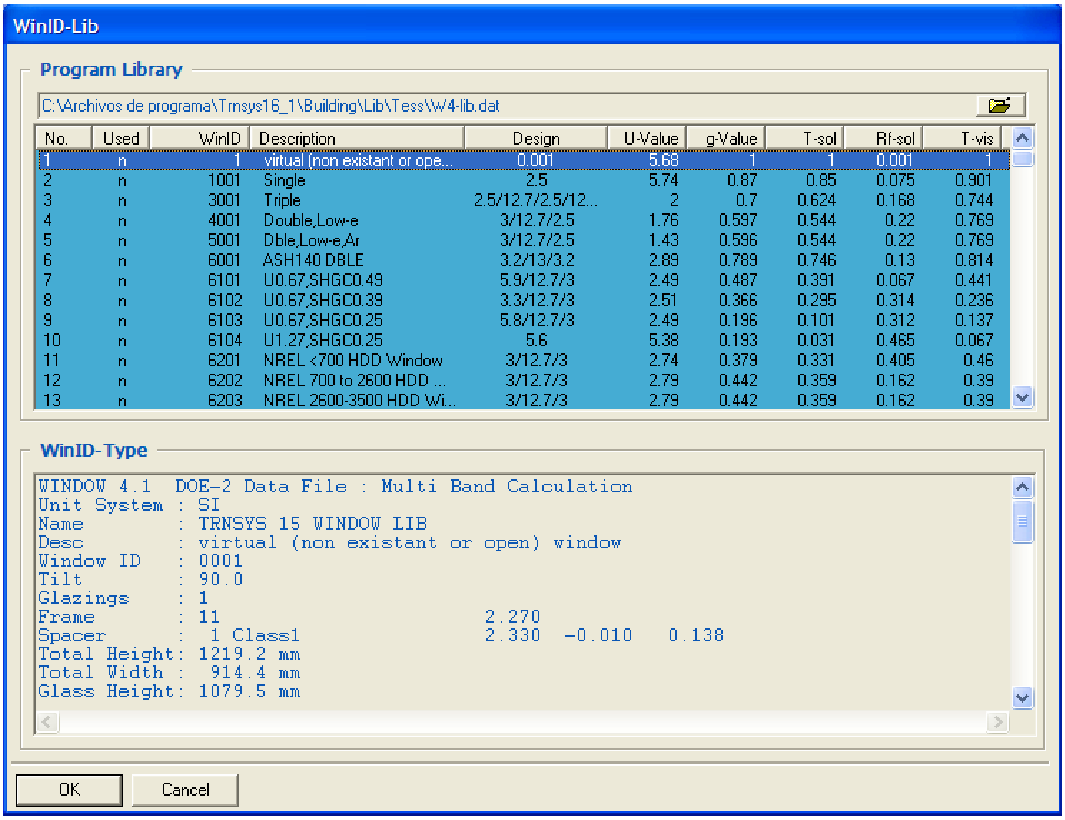


Figure. 4-2.36. The window library.

Once selected the glazing desired, the window properties described above in the *window type manager* have to be introduced.

The characteristics of the windows introduced during the simulation of the building described on chapter 3, were:

Window name	U-value (W/m^2K)	g-value	Area frame/window	Frame U-value (kJ/hm^2K)
FINESTRA	1,4	0,622	0,15	7,2

Chart 4-2.10. Characteristics of the windows.

Convective heat transfer coefficient of the window (glazing+frame): Outside: 64 kJ/hm^2K.

Inside: Internal calculation.

The last step remaining after defining the windows is to place them. To do this we have to go back to the *zone window*, select at the left box, the wall in which we want to place the window and click on add in the right box.

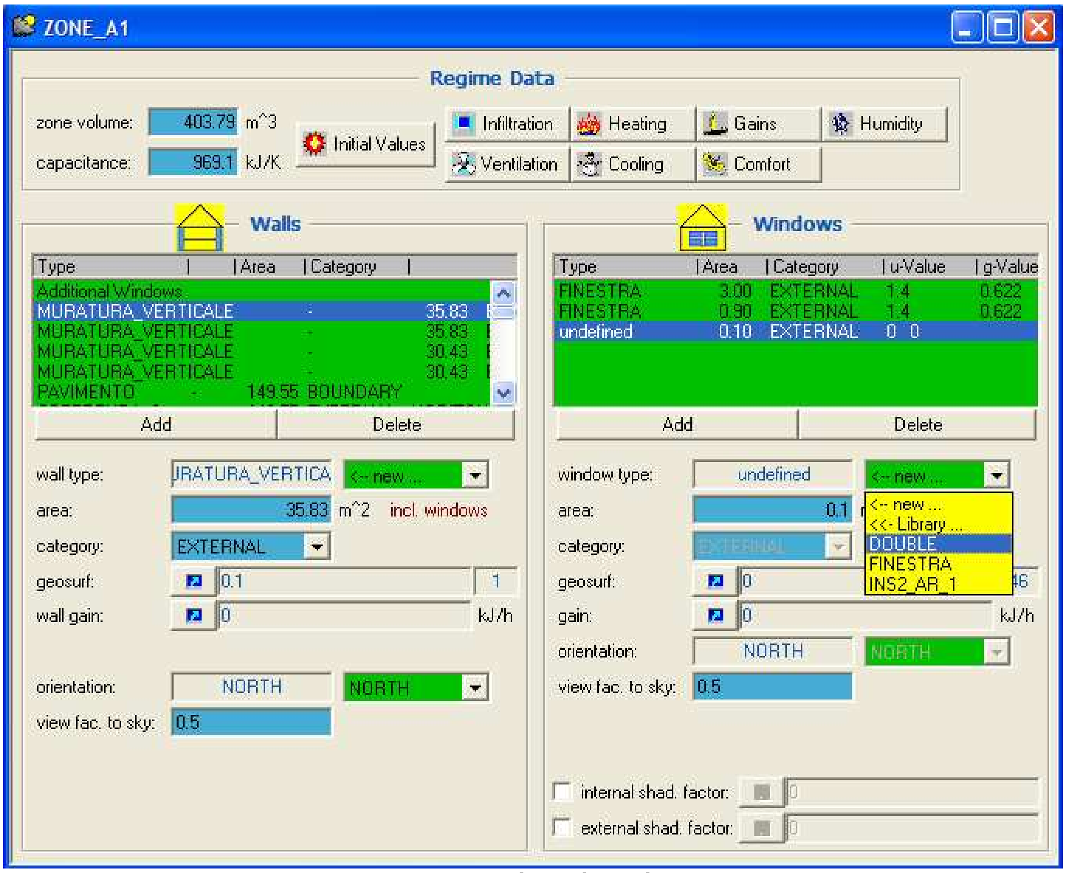


Figure. 4-2.37. Placing the windows.

Here, we have to select the window created previously at *the window type manager* by selecting it on the pull-down menu, then, we can introduce its area and other properties like gains and geosurf. TRNSYS enables us to define additional shadings at both sides of the window, as well.

Now, we can continue by defining heating, cooling and internal gains. Go to the *heating/cooling type manager* by clicking on the icons /.This will launch the windows:

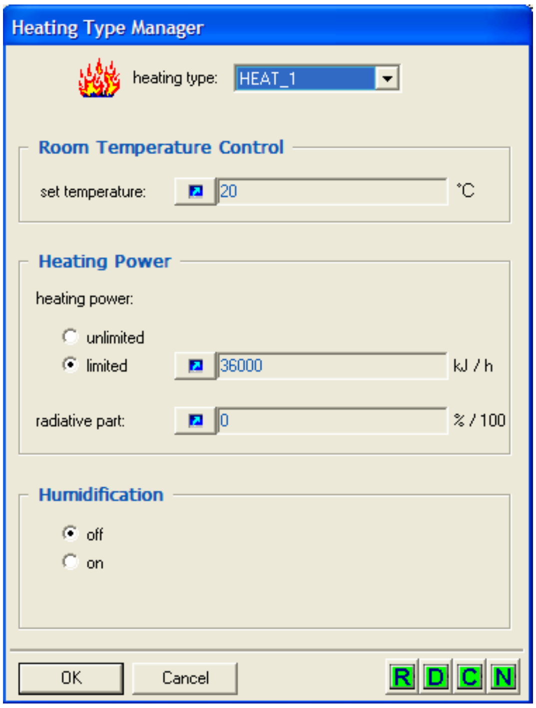


Figure. 4-2.38. The heating type manager.

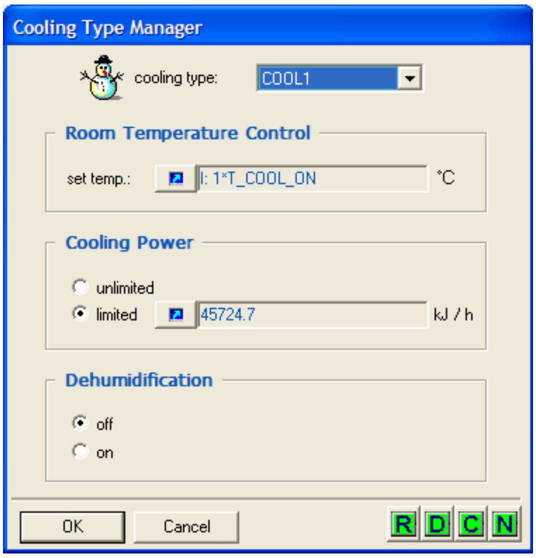


Figure. 4-2.39. The cooling type manager.

Here, we can create a new *cooling/heating type* by clicking on  (new), rename the type and introduce its properties. We can set the minimum temperature for heating, and the maximum temperature for cooling, as well as setting the maximum power of the equipment or an operation

The characteristics of the cooling/heating system simulated were:

Heating/cooling type name	System power (kJ/h) (No thermal bridges)	System power (kJ/h) (thermal bridges)
HEAT_1	21600	36000
COOLING	Unlimited	Unlimited

Chart 4-2.11. Characteristics of the cooling/heating system.

Left click on the icon  ,we will launch the *gain type manager* window. Here we can specify the internal gains generated inside a thermal zone.

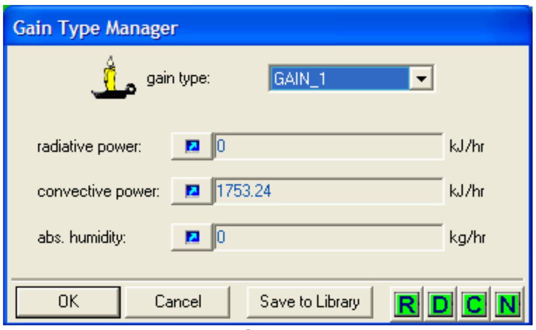


Figure. 4-2.40. The gain type manager.

The characteristics of the internal gains simulated were:

Internal gains type name	Convective power (kJ/h)
GAIN_1	1753,24

Chart 4-2.12. Characteristics of the internal gains.

Note: After generating the building, TRNSYS creates default gains for the thermal zone, we advise to remove these gains before entering the new ones.

Now, the last step remaining is to define the infiltrations:

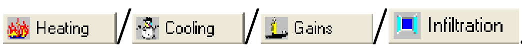
A left click on the icon , will launch the *infiltration type manager* window;

Figure. 4-2.41. The infiltration type manager.

The characteristics of the infiltrations simulated were:

Infiltration type name	Airchange of Infiltration (units/hour)
INFILTRAZIONE	0,3

Chart 4-2.13 Characteristics of the infiltrations.

To include these changes in the thermal zone, we have to go back to the *zone window* and click on the icons 

. Once launched the windows, we will be able to choose any type created previously on the pull-down menu, this will activate the type created in the thermal zone selected.

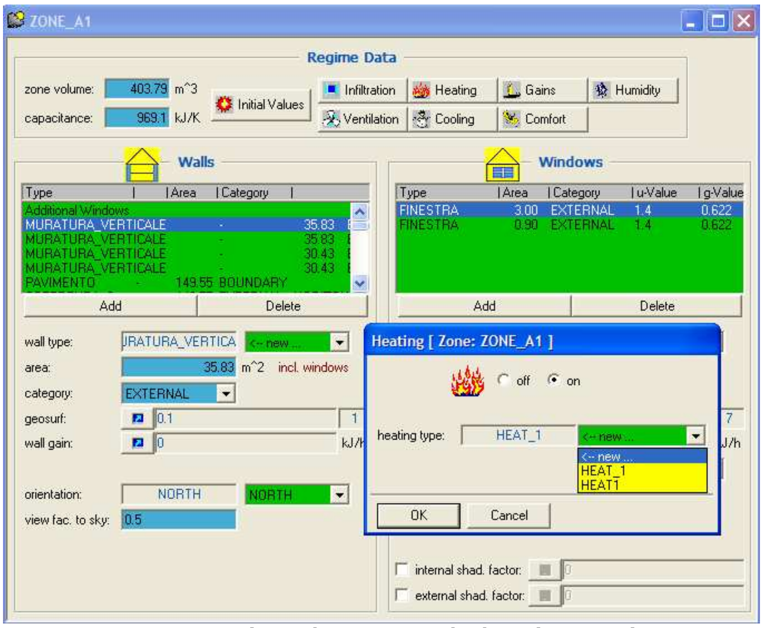


Figure. 4-2.42. Selecting heating type in the thermal zone window.

At this point, we have defined all the properties of the building so, we are ready to save. To save the file go to *File→Save as*. Here, we can introduce a new name for the file instead the default one. TRNSYS will create 4 files (*.dck,.lst,.log.bui*), the one in which we are interested in is *.bui*. This file will the one selected to load the building just created.

Note: When saving the file of the building, if we have modified the name of it, is important to remember to search for it in Simulation Studio as is explained in the figure **4-2.20** (double-clicking on the building icon, then, go to → *External files* → *Brows* → Search for the location of the file created)**.** Otherwise, we would be loading the default file created at the beginning which does not include the changes introduced with TRNBuild.

We can select the output which is going to be drawn on the Online Plotter, as well. To do this, in TRNBuild, go to *the project window* by clicking on *project* at the *TRNBuild manager window.*

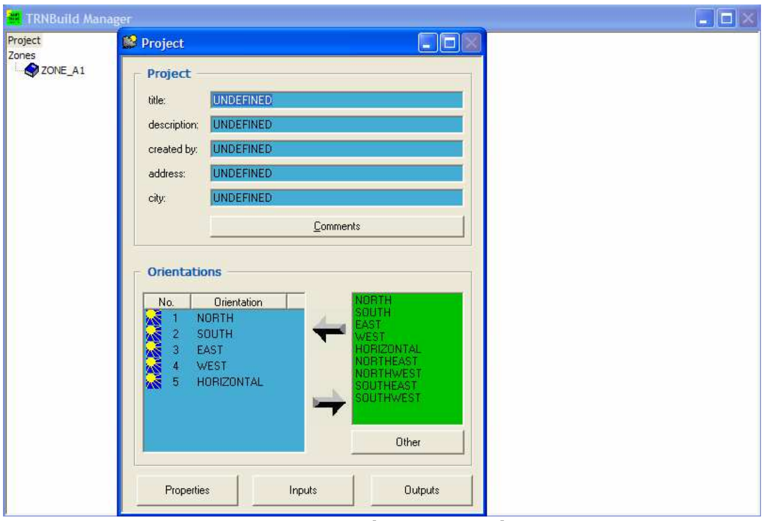


Figure. 4-2.43. The project window.

Here, in *the project window*, clicking on *outputs*, a window in which we will be able to choose any output will pop up.

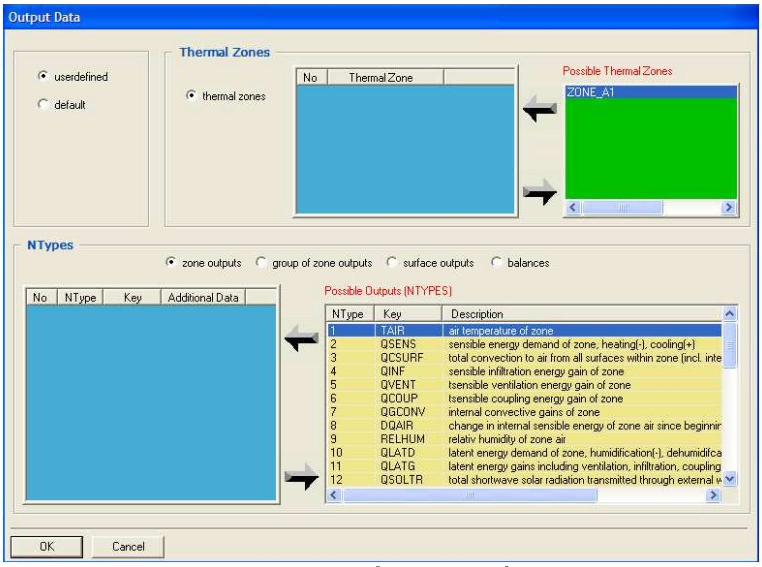


Figure. 4-2.44. Selecting output data.

Once here, we can select the output and the thermal zone wanted and, then, click on *OK*. This will create the new output.

Now, we are ready to run the simulation. We have to save the changes done in TRNBuild and go back to **Simulation Studio**. Once launched Simulation Studio, we cannot forget to load the building file created as we describe in the figure **4-2.20.** To update the output variable list created, right-click on the building icon and select: *update building variable list.*

To run the simulation press F8 or the icon , this will launch the *online plotter*. When all the calculations are completed, we have to exit from the *online plotter* and we obtain the results of the simulation by going *calculate* → *open* → *external files* →*T56_std-output.sum.* This is a monthly summary of the simulation done.

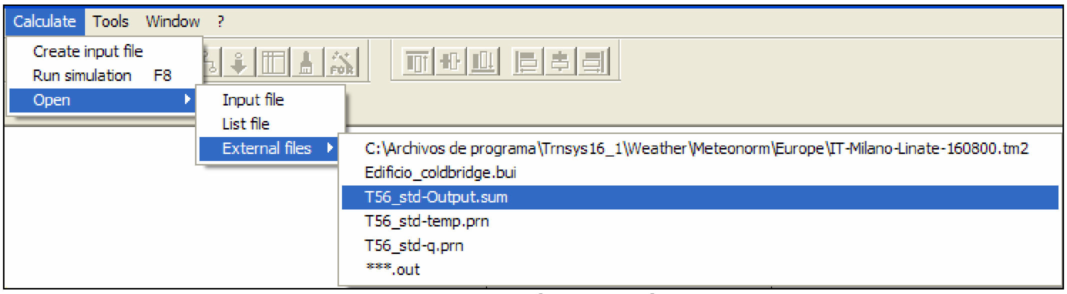


Figure. 4-2.45. Obtaining results.

5. RESULTS

This research consists of two phases:

First of all, we will compare the results obtained in the research *"Rapporto sull'analisi di codici di calcolo per la valutazione energetica degli edifici"*, with the simulation accomplished with the software TRNSYS, which is the main software used during this study.

Then, a comparison between 3 Italian cities and 3 Spanish cities will be carried out with TRNSYS. Here, is where the Italian and Spanish national regulations in Energy Performance of Buildings will be analyzed.

5.1. Phase 1: Comparison between the results obtained in TRNSYS and the report on the software for the valuation of energy performance of buildings.

In this section we will compare the results obtained in the report: *"Rapporto sull'analisi di codici di calcolo per la valutazione energetica degli edifci"*, described previously in chapter 3, with the ones obtained with TRNSYS. In order to have an actual comparison, the test building described in this report will be introduced on TRNSYS and simulated under the same boundary conditions defined in the report.

Following the same structure of the report, we will divide the comparison into two different steps:

Step 1:
Comparison between TRNSYS and the software detailed in the report starting from simplified inputs. Thermal characteristics of the components of the building's envelope described in the report have been introduced in TRNSYS. Thermal bridges have not been introduced. All the heating requirements are supplied by a standard boiler of 6 kW.

Results: Heating energy requirements in $\frac{kWh}{year \times m^2 of\_useful\_surface\_area}$ for the year overall, as the European law specifies, are given for each software studied. A numerical and graphical comparison will be detailed.

Step 2:

Comparison between TRNSYS and the software detailed in the report considering linear thermal bridges. Thermal characteristics of the components of the building's envelope described in the report have been introduced in TRNSYS. Linear thermal bridges have been included following the ISO 14683:2007 Standard. This time, winter energy requirements are supplied by a heating system of 10 kW.

Results: Heating energy requirements in $\frac{kWh}{year \times m^2 of\_useful\_surface\_area}$ for the year overall are given for each software studied. A numerical and graphical comparison will be detailed.

Note: TRNSYS has only records of the climatic data of certain locations, in which not all the cities studied in the report: *"Rapporto sull'analisi di codici di calcolo per la valutazione energetica degli edifici"* are included so, we only have been able to compare the results of the software between the following cities: Milan (Linate), Rome (Ciampino), and Palermo (Punta Raisi).

5.1.1 Building description:

It has been noticed that, according to the definition of thermal zone, which is detailed in Spanish and Italian regulations, a thermal zone is defined as volume in which temperature difference between the different rooms is no greater than 4ºK and all rooms are equipped with the same heating or cooling system.

According to this definition, the test building studied has an unique thermal zone since all rooms are set at the same temperature, all of them are powered by the same system, and wrapped by the same building thermal envelope.

So, all internal walls have been removed according to the previous definition in order to simulate an unique thermal zone. To take into account the thermal inertia of the these walls, during the simulation on TRNSYS, we have added internal walls with an overall area which equals the total surface of the walls removed.

So, in TRNSYS we will simulate a single-floor building with an area of $(11,27 \times 13,27) m^2$ and a height of 2,7m which would equal a volume of 403,79m^3.

External and internal dimensions and geometry of test building simulated on TRNSYS were (fig 5-1.1):

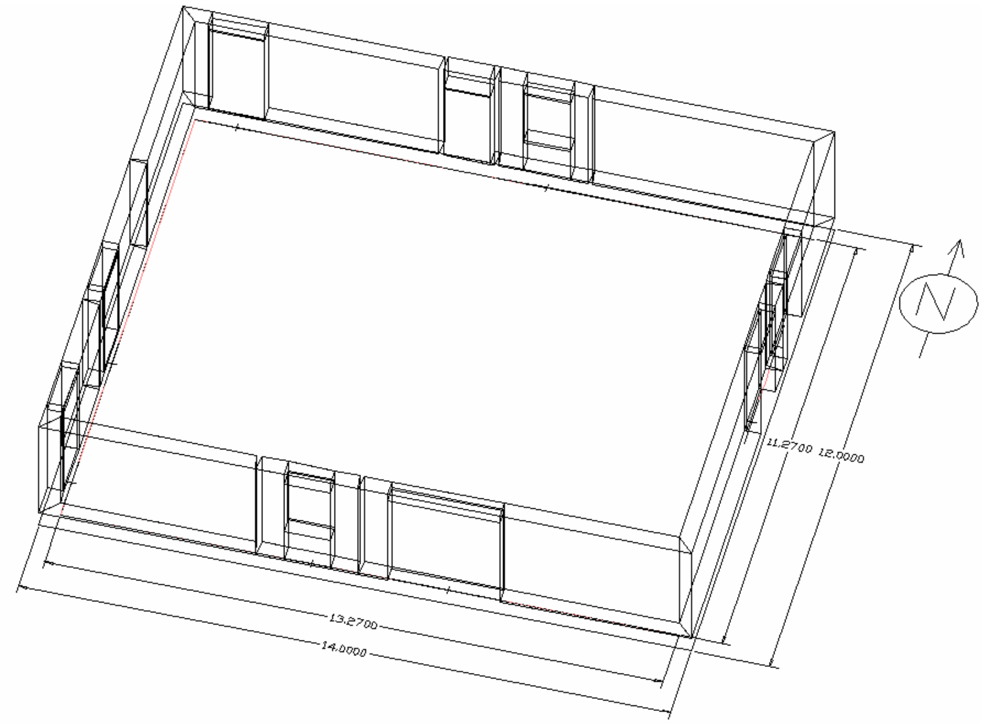


Figure 5-1.1. Internal and external dimensions of the test building.

In the following chart, thermal characteristics of building's envelope introduced on TRNSYS are detailed (5-1.1):

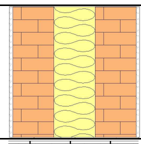
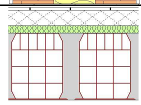
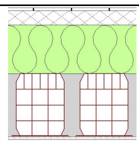
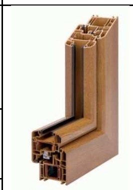
Component	Definition	Value	Thickness	Sketch
External Walls	Transmittance of the external walls	0,246 (W/m^{2}K)	0,385 m	
Floor	Transmittance of the floor	0,384 (W/m^{2}K)	0,360 m	
Roof	Transmittance of the roof	0,203 (W/m^{2}K)	0,5 m	
Windows	Transmittance of the glazing	1,4 (W/m^{2}K)	____	
	g value	0,622	____	
	Transmittance of window's frame	2,00 (W/m^{2}K)	____	
Shadings	Mean shading factor	Not introduced.		

Chart 5-1.1 Thermal characteristics of building envelope.

The characteristics of the internal walls that have been added were defined as:

U value: 1,887 (W/m^{2}K).

Thickness: 0,1 m.

Composition: Plaster mortar.
Holed brick.
Plaster mortar.

Note: As we see, there are slight differences between the transmittance values described in the report and the ones obtained with TRNSYS. TRNSYS has a special software for the calculation of wall transmittances. During the simulation with TRNSYS, all the thermal properties of the different layers of building's envelope have been introduced, as it appears in the report, the difference comes from an internal calculation in TRNSYS. Also, there is a difference between the transmittance of the glazing defined in the report (1,6 W/m^{2}K) and the one chosen in TRNSYS (1,4 W/m^{2}K). This happens because TRNSYS does not allow to introduce any value for the transmittance of a glazing manually, all the possible glazings had to be chosen from TRNSYS window library so, the closest value that we have been able to find was 1,4 W/m^{2}K.

5.1.2 Further boundary conditions:

In the next drawing, we specify location and length of the thermal bridges introduced according to the Standard UNI EN ISO 14683:

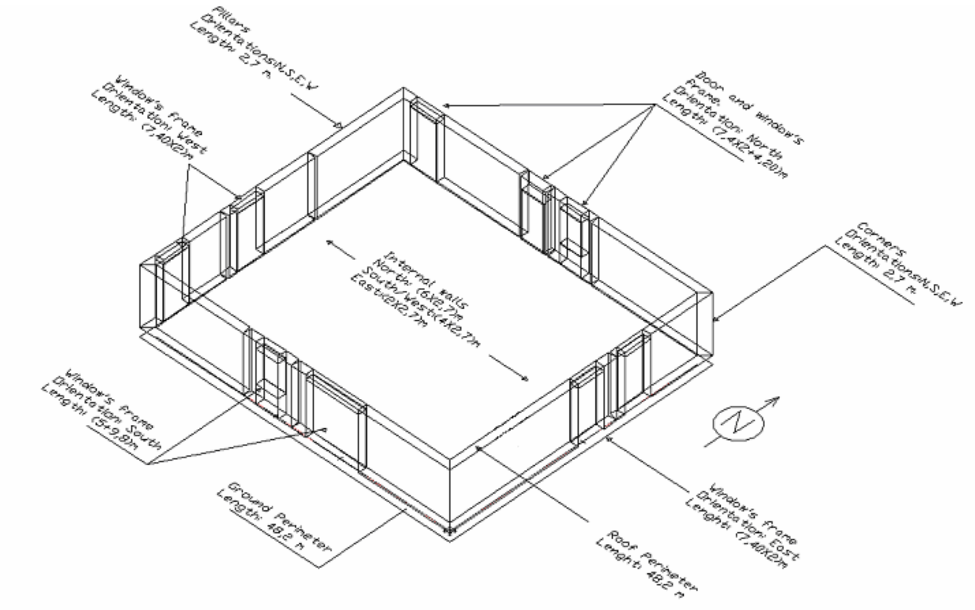


Figure 5-1.2. Situation and length of linear thermal bridges.

5.1.3 Results:

Here the results for the first phase of this research are presented. The results will be given according to the two different steps defined for each location simulated:

STEP 1:

Winter energy requirements in $\dfrac{kWh}{year \times m^2 of\_useful\_surface\_area}$ omitting linear thermal bridges and introducing a heating system of 6 kW.

For the location of **Milan-Linate**:

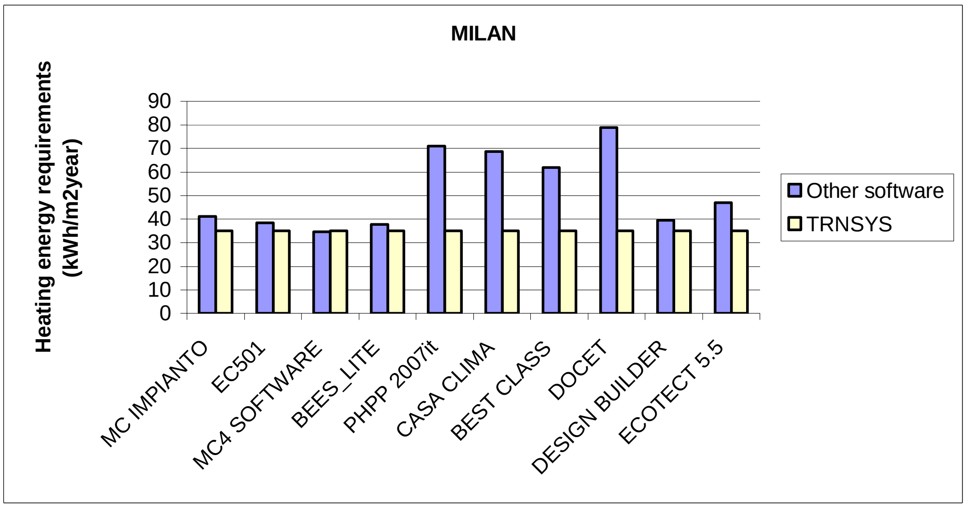


Fig.5-1.3. Winter energy requirements for the location of Milan-Linate.

Software	Heating energy requirements
MC IMPIANTO	41,18
EC501	38,52
MC4 SOFTWARE	**34,52**
BEES_LITE	37,77
PHPP 2007it	71
CASA CLIMA	68,83
BEST CLASS	61,92
DOCET	78,9
DESIGN BUILDER	39,62
ECOTECT 5.5	47,12
TRNSYS	**35**

Chart 5-1.2 Winter energy requirements for the location of Milan-Linate expressed in $\dfrac{kWh}{m^2 year}$

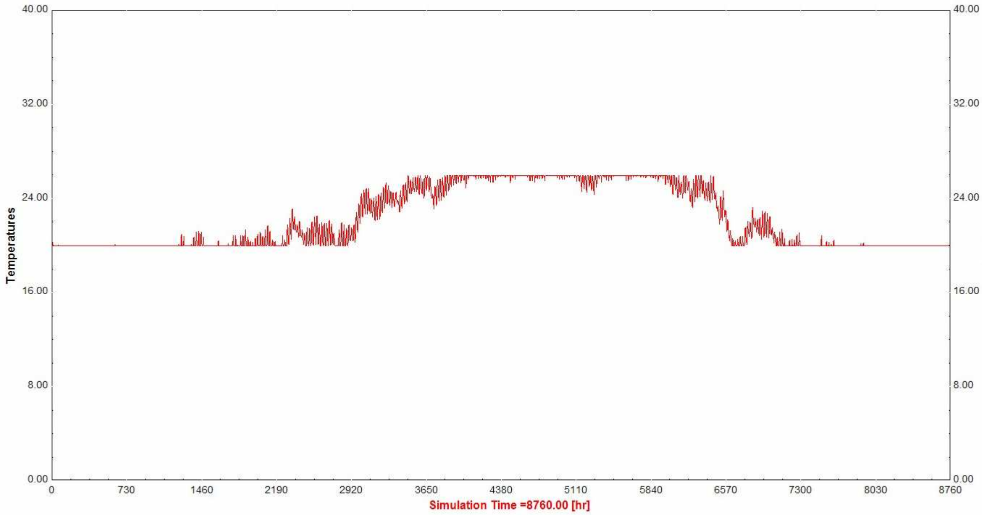


Fig.5-1.4. Temperature variation throughout a whole year for the location of Milan-Linate.

For the location of **Rome-Ciampino**:

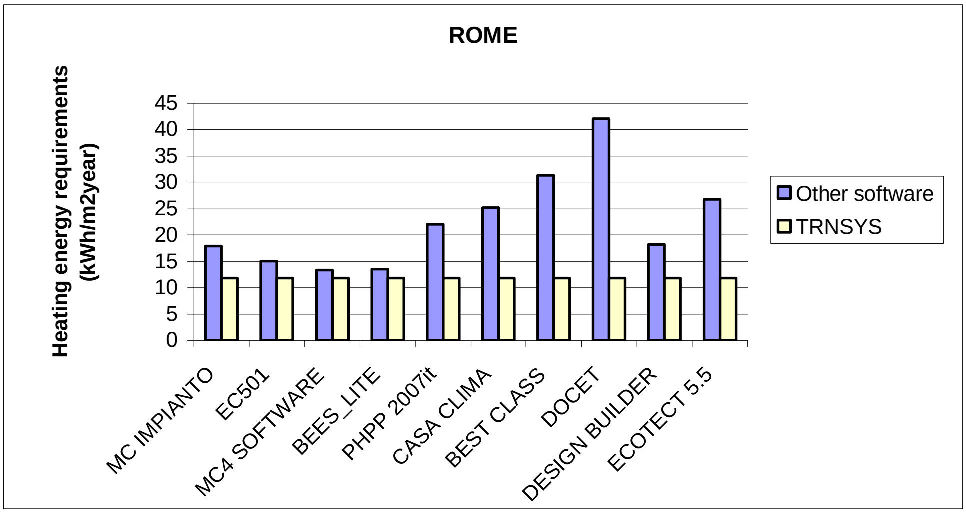


Fig.5-1.5. Winter energy requirements for the location of Rome-Ciampino.

Software	Heating energy requirements*
MC IMPIANTO	17,86
EC501	15,05
MC4 SOFTWARE	**13,38**
BEES_LITE	13,52
PHPP 2007it	22
CASA CLIMA	25,21
BEST CLASS	31,3
DOCET	42,1
DESIGN BUILDER	18,22
ECOTECT 5.5	26,81
TRNSYS	**11,8**

Chart 5-1.3. Winter energy requirements for the location of Rome-Ciampino expressed in $\frac{kWh}{m^2 year}$

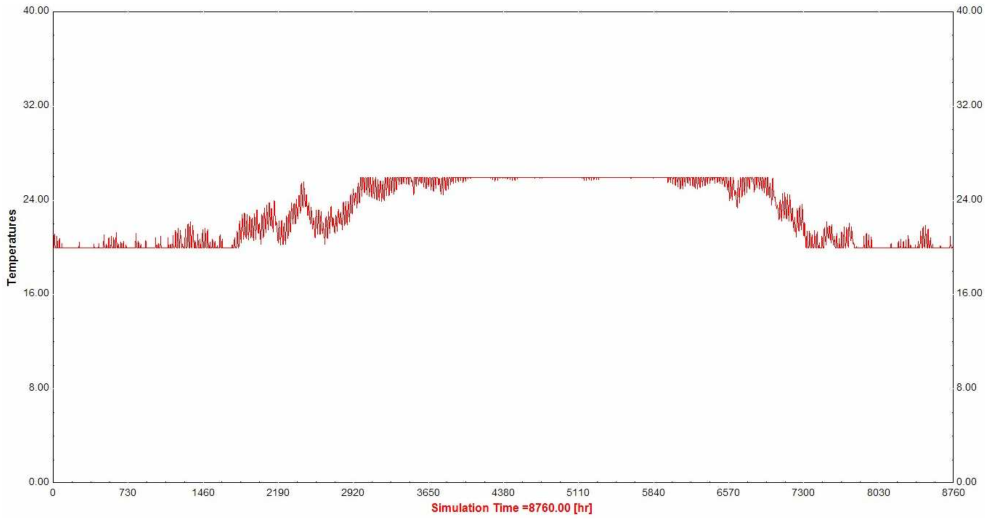


Fig.5-1.6. Temperature variation throughout a whole year for the location of Rome-Ciampino.

For the location of **Palermo-Punta Raisi**:

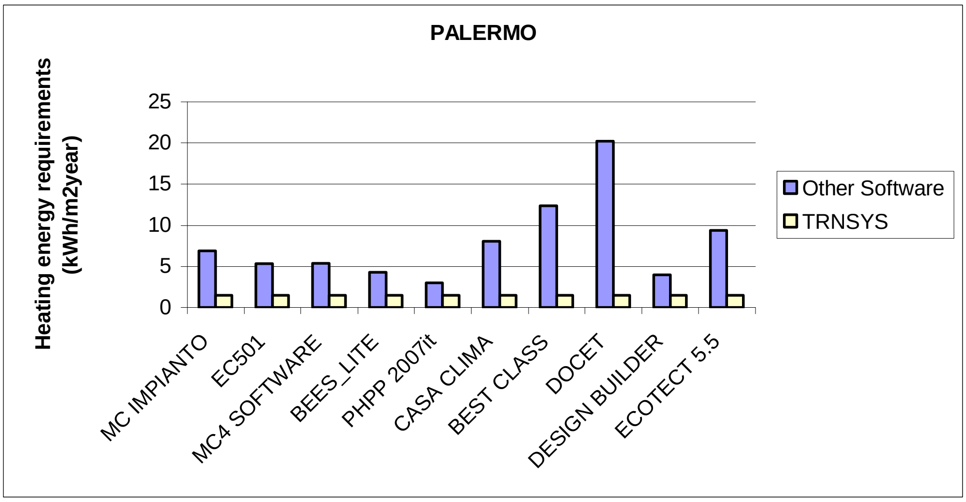


Fig.5-1.7. Winter energy requirements for the location of Palermo-Punta Raisi.

Software	Heating energy requirements*
MC IMPIANTO	6,87
EC501	5,28
MC4 SOFTWARE	**5,4**
BEES_LITE	4,3
PHPP 2007it	3
CASA CLIMA	8
BEST CLASS	12,37
DOCET	20,2
DESIGN BUILDER	3,95
ECOTECT 5.5	9,41
TRNSYS	**1,48**

Chart 5-1.4. Winter energy requirements for the location of Palermo-Punta Raisi expressed in $\frac{kWh}{m^2 year}$

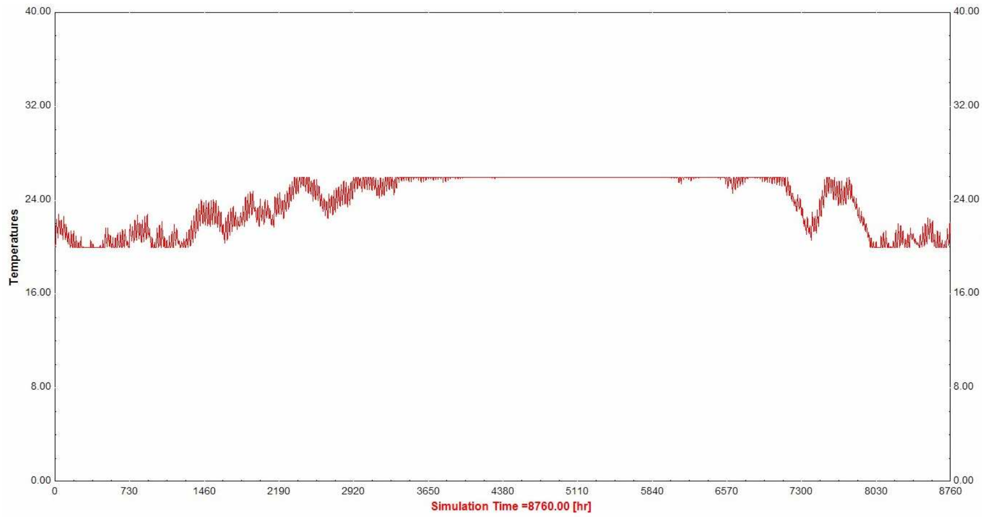


Fig.5-1.8. Temperature variation throughout a whole year for the location of Palermo-Punta Raisi.

STEP 2:

In this step winter energy requirements in $\frac{kWh}{year \times m^2 of\_useful\_surface\_area}$ are reported. Linear thermal bridges were included as the European standard specifies which is detailed in the chapter: "Report on the software for the valuation of energy performance of buildings". Energy requirements are supplied by a heating system of 10kW.

For the location of **Milan-Linate**:

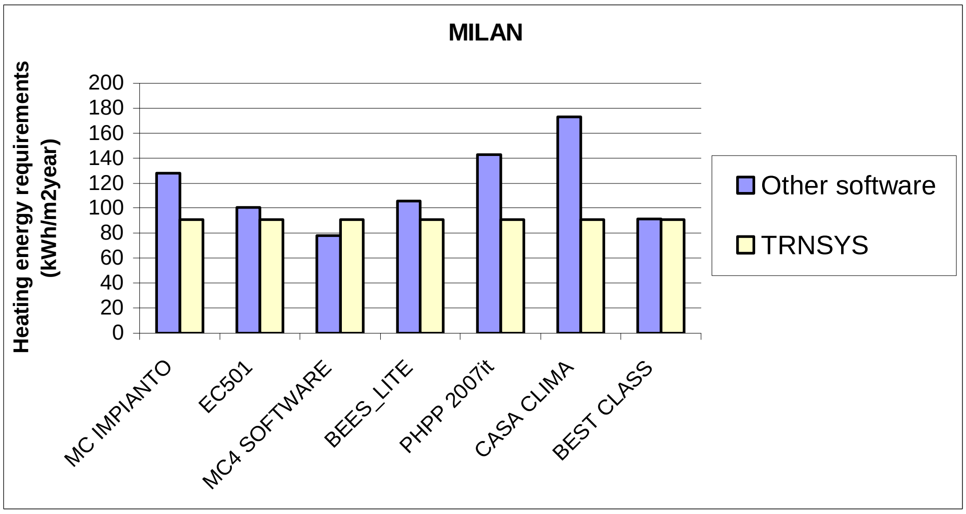


Fig.5-1.9. Winter energy requirements in the location of Milan-Linate with thermal bridges.

Software	Heating energy requirements*
MC IMPIANTO	128,1
EC501	100,52
MC4 SOFTWARE	**78,13**
BEES_LITE	105,6
PHPP 2007it	143
CASA CLIMA	173
BEST CLASS	91,1
TRNSYS	**90,87**

Chart 5-1.5. Winter energy requirements for the location of Milan-Linate with thermal bridges expressed in $\frac{kWh}{m^2 year}$

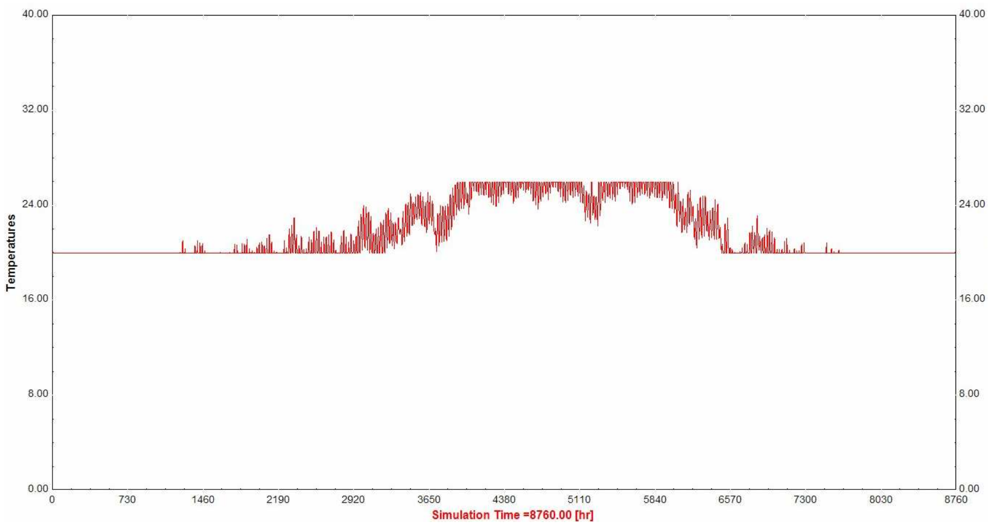


Fig.5.10. Temperature variation throughout a whole year for the location of Milan-Linate including thermal bridges.

For the location of **Rome-Ciampino**:

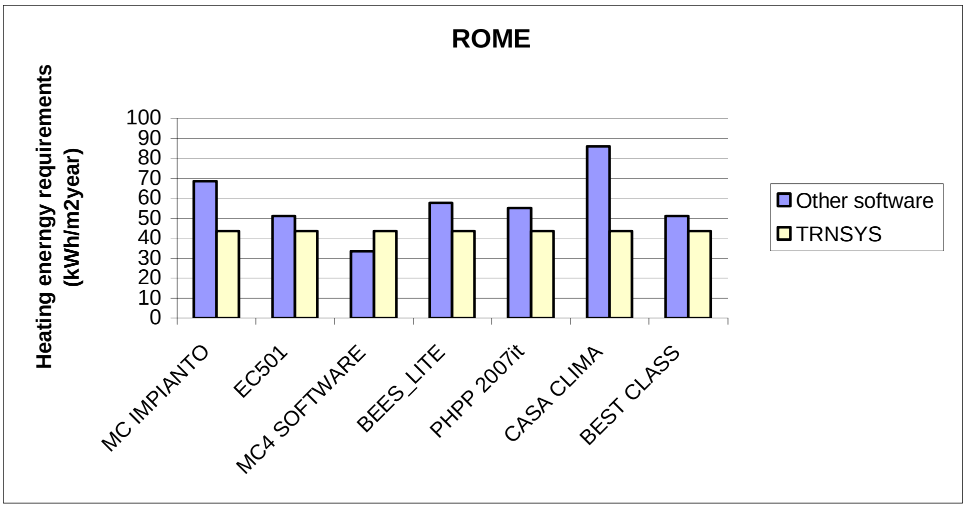


Fig.5-1.11. Winter energy requirements in the location of Rome-Ciampino with thermal bridges.

Software	Heating energy requirements*
MC IMPIANTO	68,51
EC501	50,9
MC4 SOFTWARE	**33,36**
BEES_LITE	57,6
PHPP 2007it	55
CASA CLIMA	86
BEST CLASS	51
TRNSYS	**43,44**

Chart 5-1.6. Winter energy requirements for the location of Rome-Ciampino with thermal bridges expressed in $\frac{kWh}{m^2 year}$

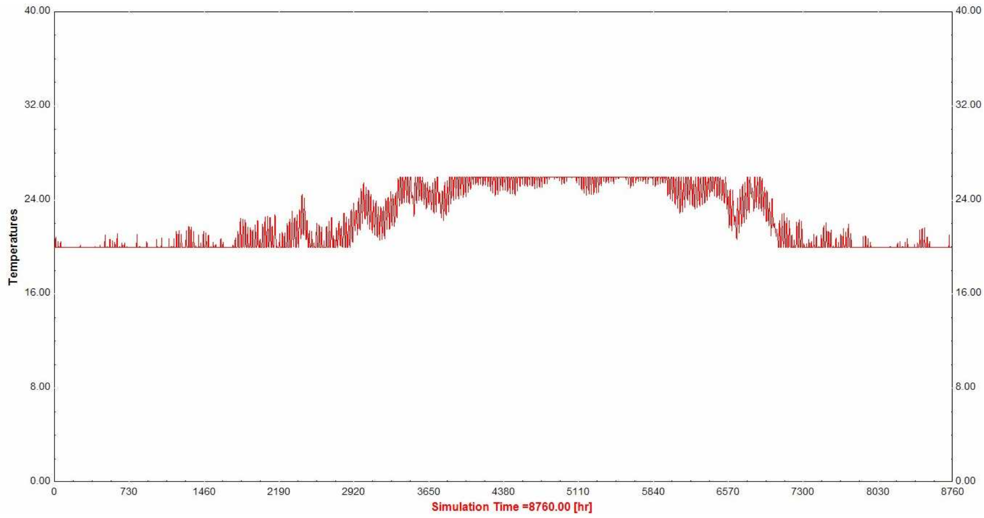


Fig.5-1.12. Temperature variation throughout a whole year for the location of Rome-Ciampino including thermal bridges.

For the location of **Palermo-Punta Raisi**:

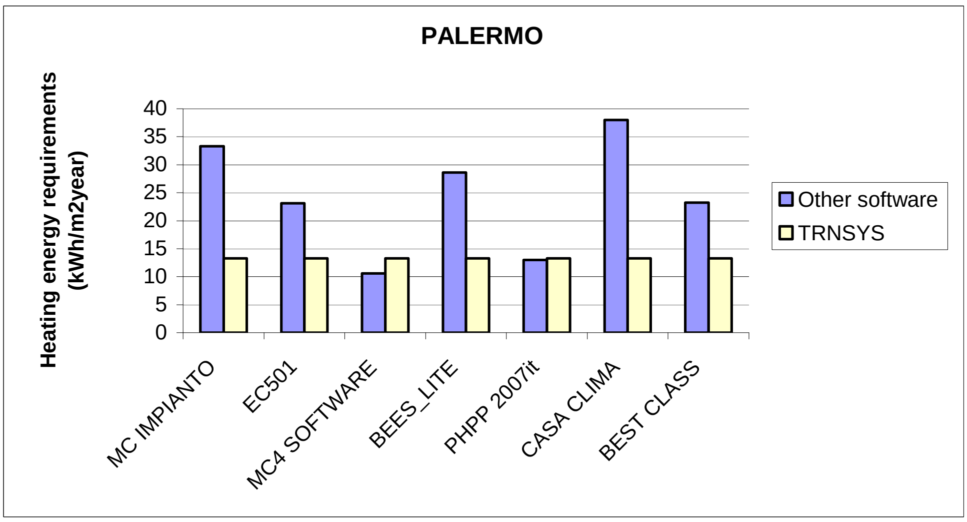


Fig.5-1.13. Winter energy requirements in the location of Palermo with thermal bridges.

Software	Heating energy requirements*
MC IMPIANTO	33,29
EC501	23,11
MC4 SOFTWARE	**10,61**
BEES_LITE	28,63
PHPP 2007it	13
CASA CLIMA	38
BEST CLASS	23,24
TRNSYS	**13,3**

Chart 5-1.7. Winter energy requirements for the location of Palermo with thermal bridges expressed in $\frac{kWh}{m^2 year}$

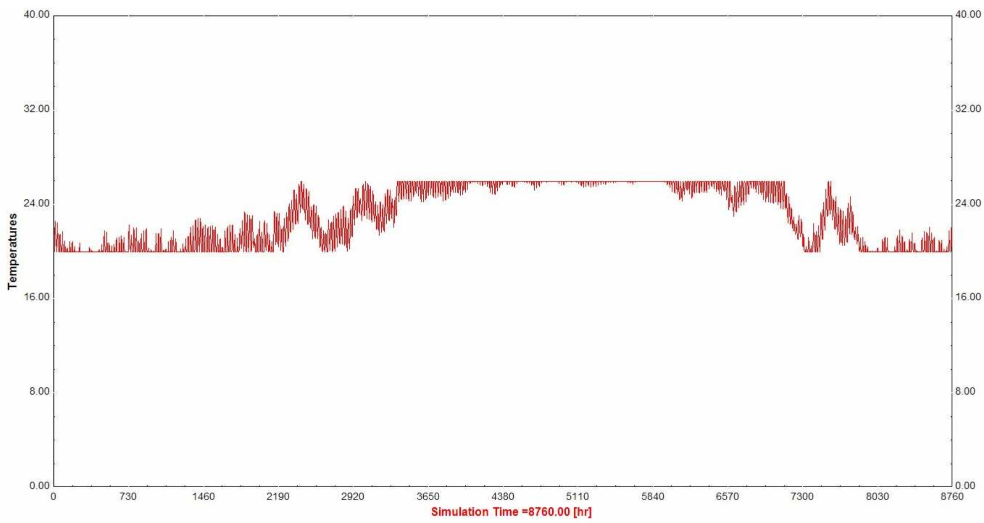


Fig.5-1.14. Temperature variation throughout a whole year for the location of Palermo-Punta Raisi including thermal bridges

5.2. Phase 2: Comparison between Spanish and Italian regulations.

In this section we will analyse and compare the national regulations of Italy and Spain according to the transposition of the Directive 2002/91/EC on energy efficiency in buildings. This will be done by selecting cities with similar energy requirements from both countries and simulating the same test building under the existing regulations in the two countries. The regulations applied to each country have been described in the previous chapter of: "Regulations analyzed".

This section, follows the same structure as the previous section, i.e., the procedure will be divided into two different steps:

Step 1:
The simulation will be carried out without considering thermal bridges with a heating system of 6 kW.

Step 2:
The simulation will be carried out introducing thermal bridges with a heating system of 10 kW.

5.2.1 Building' s characteristics:

The test building chosen, will be the same as the described in the chapter: "Report on the software for the valuation of energy performance of buildings" of the present project.
The only thing of the test building that has been changed was the insulation thickness of each part of building's envelope, which has been changed depending on the country and climatic zone that has been studied in order to fulfil national regulations of each country.

According to this, the constructive characteristics of building's thermal envelope are:

Vertical walls:

Description:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m^3)	Specific heat (kJ/kgK)
External plaster	0,015	0,900	1800	0,84
Brick wall	0,12	0,260	600	0,84
Fibreglass	Variable	0,039	80	1,03
Brick wall	0,12	0,360	1000	0,84
Internal plaster	0,010	0,900	1800	0,84

Chart 5-2.1 Vertical walls layer configuration.

Roof:

Description:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m^3)	Specific heat (kJ/kgK)
Tile	0,01	0,720	1800	0,84
Concrete	0,05	0,930	1800	0,88
Expanded polyethylene	Variable	0,048	33	1,45
Cement	0,22	0,700	1450	0,84
Internal plaster	0,010	1,400	2000	0,84

Chart 5-2.2 Roof layer configuration

Floor:

Description:

Layer (from outside to inside)	Layer thickness (m)	λ (W/mK)	Density (Kg/m^3)	Specific heat (kJ/kgK)
Solaio latero cemento	0,22	0,7	1450	0,84
Polistirene esp. estruso	Variable	0,039	25	1,25
Massetto in cls	0,05	0,930	1800	0,88
Piastrelle di cotto	0,01	0,720	1800	0,84

Chart 5-2.3 Floor layer configuration

Glazing:

Glazing properties have been changed in each different situation depending on the regulation of each country and thermal zone.

Internal walls:

Spanish and Italian regulations do not specify which is the maximum transmittance permitted on internal walls. This happens because internal walls do not compose building's thermal envelope so, the same internal walls have been taken in all the simulations done.

Internal walls characteristics.

U value:1,887 (W/m^{2}K).

Thickness: 0,1 m.

Composition: Plaster mortar.
Holed brick.
Plaster mortar.

Characteristics of the heating system:

In order to have an actual comparison between the regulations of the two countries, the same heating and cooling system characteristics have been introduced in TRNSYS for all the simulations. These are defined here;

- Infiltration: 0,3 units/hour.
- No mechanical ventilation.
- Heating: No thermal bridges: Power limited at 6 kW.
  With thermal bridges: Power limited at 10 kW.
  Humidification: 40%.
  Temperature set at 20ºC.
- Gains: Recommendation CTI-03.
  Gains = 3,278 W/m^2
- Cooling: Temperature set at 26ºC
  Dehumidification: 60%
  Unlimited power.

5.2.2 Further boundary conditions:

Linear thermal bridges were introduced as explained in the chapter: “Report on the software for the valuation of energy performance of buildings” at the locations shown on the figure 5-1.2.

5.2.3 Cities chosen:

In order to compare the regulations for both countries, the same climatic data should be simulated on each case, i.e., for every pair of cities compared, a similar climate data must be taken. To do this, we use the definition of a degree day.

A degree-day is a measure of heating that enables us to tell how cold is a certain place, and gives an idea of how much energy is required in order to heat a building located at this place. There are lots of charts with records of average degree-day in the current literature. Unfortunately, we can not use this data on this project because is not representative of weather data existing on TRNSYS ,i.e., TRNSYS weather data has different temperature records than the existing on European charts. Also, European charts of degree-day records are calculated in a different basis depending on the country. For instance, Italian charts are calculated in a 15 basis, and Spanish charts in a 20 basis. Thus, we needed to create degree-day files with TRNSYS weather data. We have managed to do this, by importing TRNSYS weather files, taking hourly-temperature (an overall of 8760 temperatures) files from the TMY2 files existing on TRNSYS library and design a sheet with the program MICROSOFT EXCEL, which calculates degree-day files for all the cities desired.

Is at this point, taking TRNSYS data, when we can have an actual comparison of the different weather records existing on TRNSYS.

So, the procedure will be the following:

- Take and select hourly-temperatures from TRNSYS TMY2 files.
- Import these files with MS-EXCEL.
- Calculate degree-day data with this new hourly-temperature files for all Spanish and Italian cities existing on TRNSYS files.
- Compare and select all cities with similar degree-days.
- From all the cities selected, take three which represent three different climate-zones.
- Start the simulation with TRNSYS, using Spanish and Italian regulations and standards were necessary.
- Compare and discuss the results.

In the next picture, taken from TRNSYS user's manual, cities which are in TRNSYS current weather data base are represented. Black dots represent stations for which solar radiation data was recorded on site, white dots represent other locations.

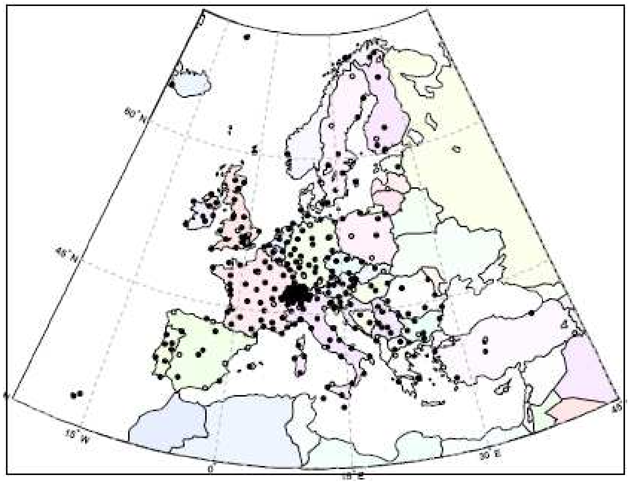


Figure 5-2.1. TRNSYS weather data locations.

As we see, there are plenty of European cities with known weather data base. Mainly in the centre of Europe. In Mediterranean countries there are not so much, but they are enough for this study.

After have followed the proceeding detailed above, these are the cities selected enclosed with their calculated degree-days:

Climatic zone 1:
Palermo-Punta Raisi= 256 dd.
Almeria = 238 dd.

Climatic zone 2:
Roma-Ciampino = 992 dd.
Toledo = 976 dd.

Climatic zone 3:
Madrid-Barajas = 1328 dd.
Trieste = 1186 dd.

Now, the standards and regulations for each city selected are detailed:

ALMERIA:

Climatic Zone A4:

Transmittances according with the Spanish regulation: CTE 2007-2008

Building envelope:

External walls: Ulim= 0.94 W/m^{2}K

Floor: Ulim= 0.53 W/m^{2}K

Roof: Ulim= 0.50 W/m^{2}K

Maximum solar correction factor of holes: Not applicable

Windows:

Spanish regulation distinguishes different maximum transmittances permitted depending on the proportion of glazing and orientation on walls:

ZONA CLIMÁTICA A4

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,94 W/m^{2}K**
Transmitancia límite de suelos	**U_{Slim}: 0,53 W/m^{2}K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,50 W/m^{2}K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,29**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	5,7	5,7	5,7	5,7	-	-	-	-	-	-
de 11 a 20	4,7 (5,6)	5,7	5,7	5,7	-	-	-	-	-	-
de 21 a 30	4,1 (4,6)	5,5 (5,7)	5,7	5,7	-	-	-	0,56	-	0,57
de 31 a 40	3,8 (4,1)	5,2 (5,5)	5,7	5,7	0,57	-	0,58	0,43	0,59	0,44
de 41 a 50	3,5 (3,8)	5,0 (5,2)	5,7	5,7	0,47	-	0,48	0,35	0,49	0,37
de 51 a 60	3,4 (3,6)	4,8 (4,9)	5,7	5,7	0,40	0,55	0,42	0,30	0,42	0,32

[1] En los casos en que la transmitancia media de los muros de fachada U_{Mm}, definida en el apartado 3.2.2.1, sea inferior a 0,67 W/m^{2}K se podrá tomar el valor de U_{Hlim} indicado entre paréntesis para las zonas climáticas A3 y A4.

In the building studied, there is a different proportion of glazing on each wall depending on the orientation, as is detailed in the following chart;

Orientation	Fraction of glazing on wall
North	11%
South	21%
East	20%
West	20%

According to the regulation, the maximum transmittance of the windows depending on the orientation of each wall is:

Orientation	Maximum transmittance (W/m^{2}K)
North	4,7
South	5,7
East	5,7
West	5,7

Simulation was performed with the numerical code TRNSYS. This program has a wide window library on which all windows characteristics can be found. Nevertheless, for the same reason explained recently, TRNSYS windows library does not include all the window transmittances needed, because of this, an approximation which fulfil Spanish regulation had to be done.

Thus, windows chosen at TRANSYS library were:

Orientation	Transmittance (W/m^{2}K)
North	3,44
South	5,68
East	5,68
West	5,68

PALERMO Punta-Raisi:

Climatic Zone B:

Transmittances according with the Italian regulation nº 311.

External vertical walls: Ulim = 0,54 W/m^{2}K

Floor: Ulim = 0,55 W/m^{2}K

Roof: Ulim = 0,42 W/m^{2}K

Glazing: Ulim = 3,4 W/m^{2}K

Data taken from regulation 311:

TABELLA 4.b	**Vetri** Valori limite della trasmittanza termica U espressa in W/m^{2}K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^{2}K)	**Dall' 1 luglio 2008** U (W/m^{2}K)	**Dall' 1 gennaio 2011** U (W/m^{2}K)
A	5.0	4.5	3.7
B	4.0	3.4	2.7
C	3.0	2.3	2.1
D	2.6	2.1	1.9
E	2.4	1.9	1.7
F	2.3	1.7	1.3

Walls:

TABELLA 2.1	**Strutture opache verticali**, Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.85	0.72	0.62
B	0.64	0.54	0.48
C	0.57	0.46	0.40
D	0.50	0.40	0.36
E	0.46	0.37	0.34
F	0.44	0.35	0.33

Roof:

TABELLA 3.1	**Coperture** Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.80	0.42	0.38
B	0.60	0.42	0.38
C	0.55	0.42	0.38
D	0.46	0.35	0.32
E	0.43	0.32	0.30
F	0.41	0.31	0.29

Floor:

TABELLA 3.2	**Pavimenti verso locali non riscaldati o verso l'esterno** Valori limite della trasmittanza termica U espressa in W/m^2K		
Zona climatica	**Dall' 1 gennaio 2006** U (W/m^2K)	**Dall' 1 gennaio 2008** U (W/m^2K)	**Dall' 1 gennaio 2010** U (W/m^2K)
A	0.80	0.74	0.65
B	0.60	0.55	0.49
C	0.55	0.49	0.42
D	0.46	0.41	0.36
E	0.43	0.38	0.33
F	0.41	0.36	0.32

Windows chosen at TRNSYS library were:

Orientation	Transmittance (W/m^2K)
North	3,25
South	3,25
East	3,25
West	3,25

TOLEDO:

Climatic Zone C4:

Transmittances according with the Spanish regulation: CTE 2007-2008.

ZONA CLIMÁTICA C4

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	U_{Mlim}: **0,73 W/m^2 K**
Transmitancia límite de suelos	U_{Slim}: **0,50 W/m^2 K**
Transmitancia límite de cubiertas	U_{Clim}: **0,41 W/m^2 K**
Factor solar modificado límite de lucernarios	F_{Llim}: **0,27**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	4,4	4,4	4,4	4,4	-	-	-	-	-	-
de 11 a 20	3,4 (4,2)	3,9 (4,4)	4,4	4,4	-	-	-	-	-	-
de 21 a 30	2,9 (3,3)	3,3 (3,8)	4,3 (4,4)	4,3 (4,4)	-	-	-	0,54	-	0,56
de 31 a 40	2,6 (2,9)	3,0 (3,3)	3,9 (4,1)	3,9 (4,1)	0,54	-	0,56	0,41	0,57	0,43
de 41 a 50	2,4 (2,6)	2,8 (3,0)	3,6 (3,8)	3,6 (3,8)	0,47	-	0,46	0,34	0,47	0,35
de 51 a 60	2,2 (2,4)	2,7 (2,8)	3,5 (3,6)	3,5 (3,6)	0,38	0,53	0,39	0,29	0,40	0,30

[1] En los casos en que la transmitancia media de los muros de fachada U_{Mm}, definida en el apartado 3.2.2.1, sea inferior a 0,52 W/m^{2}K se podrá tomar el valor de U_{Hlim} indicado entre paréntesis para las zonas climáticas C1, C2, C3 y C4.

Building envelope:

External walls: Ulim=0,73 W/m^{2}K

Floor: Ulim=0,50 W/m^{2}K

Roof: Ulim=0,41 W/m^{2}K

Maximum solar correction factor of holes: Not applicable.

For glazing proportion defined previously:

Orientation	Fraction of glazing on wall	Maximum transmittance permitted (W/m^{2}K)
North	11%	3,4
South	21%	4,3
East	20%	4,4
West	20%	4,4

Windows chosen from TRNSYS window library:

Orientation	Transmittance (W/m^{2}K)
North	3,25
South	3,44
East	3,44
West	3,44

ROMA CIAMPINO:

Climatic Zone: D

Transmittances according with the Italian regulation nº 311.

Building envelope

External vertical walls: Ulim = 0,40 W/m^{2}K

Floor: Ulim = 0,41 W/m^{2}K

Roof: Ulim = 0,35 W/m^{2}K

Glazing: Ulim = 2,1 W/m^{2}K

Windows chosen at TRNSYS library were:

Orientation	Transmittance (W/m^{2}K)
North	2
South	2
East	2
West	2

MADRID Barajas:

Climatic Zone: D3

Building envelope

External vertical walls: Ulim = 0,66 W/m^{2}K.

Floor: Ulim = 0,49 W/m^{2}K.

Roof: Ulim = 0,38 W/m^{2}K.

Maximum solar correction factor of holes: Not applicable.

ZONA CLIMÁTICA D3

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	U_{Mlim}: 0,66 W/m^2 K
Transmitancia límite de suelos	U_{Slim}: 0,49 W/m^2 K
Transmitancia límite de cubiertas	U_{Clim}: 0,38 W/m^2 K
Factor solar modificado límite de lucernarios	F_{Llim}: 0,28

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	3,5	3,5	3,5	3,5	-	-	-	-	-	-
de 11 a 20	3,0 (3,5)	3,5	3,5	3,5	-	-	-	-	-	-
de 21 a 30	2,5 (2,9)	2,9 (3,3)	3,5	3,5	-	-	-	0,54	-	0,57
de 31 a 40	2,2 (2,5)	2,6 (2,9)	3,4 (3,5)	3,4 (3,5)	-	-	-	0,42	0,58	0,45
de 41 a 50	2,1 (2,2)	2,5 (2,6)	3,2 (3,4)	3,2 (3,4)	0,50	-	0,53	0,35	0,49	0,37
de 51 a 60	1,9 (2,1)	2,3 (2,4)	3,0 (3,1)	3,0 (3,1)	0,42	0,61	0,46	0,30	0,43	0,32

For glazing proportion on walls defined previously:

Orientation	Fraction of glazing on wall	Maximum transmittance permitted (W/m^{2}K)
North	11%	3,0
South	21%	3,5
East	20%	3,5
West	20%	3,5

Windows chosen from TRNSYS window library:

Orientation	Transmittance (W/m^{2}K)
North	3,0
South	3,44
East	3,44
West	3,44

TRIESTE:

Climatic Zone: E

Data taken from Italian regulation nº 311.

Building envelope:

External vertical walls: Ulim = 0,37 W/m^{2}K

Floor: Ulim = 0,38 W/m^{2}K

Roof: Ulim = 0,32 W/m^{2}K

Glazing: Ulim = 1,9 W/m^{2}K

Windows chosen at TRNSYS library were:

Orientation	Transmittance (W/m^{2}K)
North	1,9
South	1,9
East	1,9
West	1,9

5.2.4 Results:

A total number of 12 simulations have been done, 6 for the Italian regulation (Decree n. 192/05-2008) and 6 for the Spanish regulation (CTE). For each simulation, energy requirements for heating, cooling have been obtained, other building's gains such as solar radiation, internal gains and infiltration are detailed, as well. It is also included, a graphic with the total energy consumption for each comparison between cities,

Each chart compares annual energy requirements for cities with similar degree-days in $\frac{kWh}{year \times m^2 of\_useful\_surface\_area}$.

Step 1:

<u>Almeria Vs. Palermo:</u>

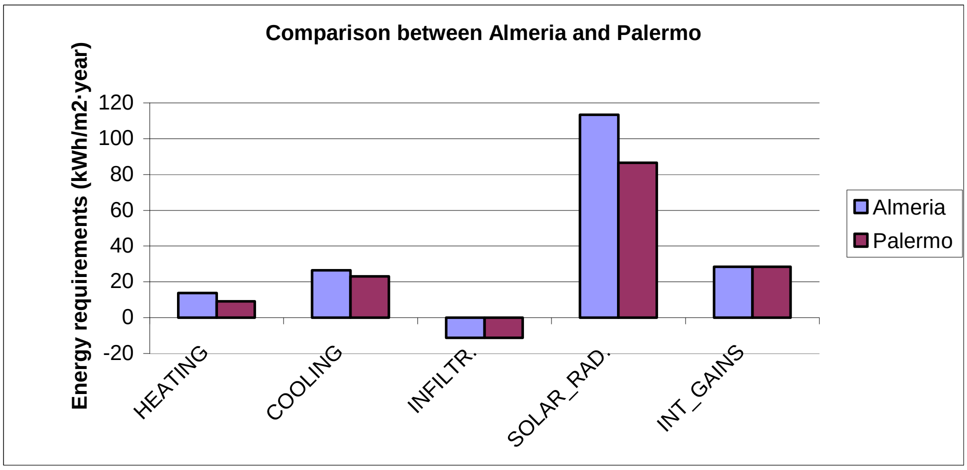


Figure 5-2.2. Energy requirements and gains obtained for the comparison between Almeria and Palemo.

Energy requirement	Heating (kWh/m^{2}year)	Cooling (kWh/m^{2}year)	Total energy consumption (kWh/m^{2}year)
Almería	13,7	26,5	40,2
Palermo	9,13	23,1	32,2

Chart 5-2.4. Heating and cooling requirements for the comparison between Almeria and Palemo.

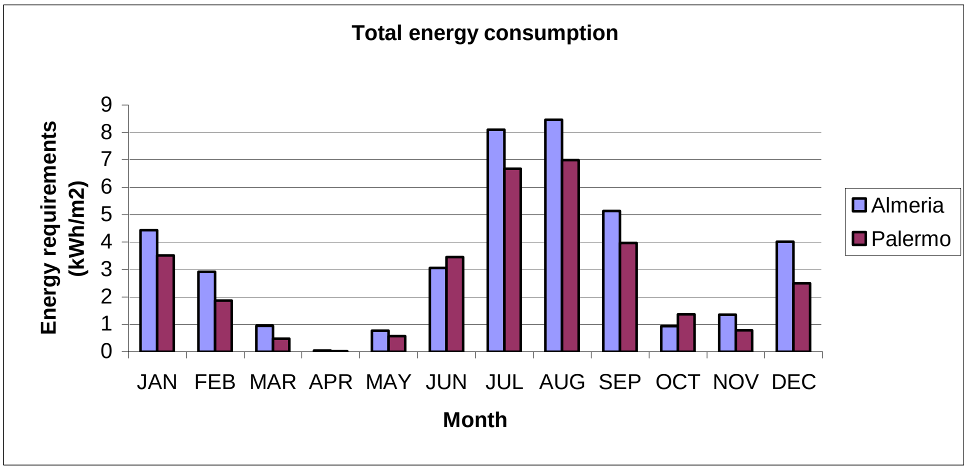


Figure 5-2.3.Total energy consumption obtained for the comparison between Almeria and Palemo

Toledo Vs. Rome-Ciampino:

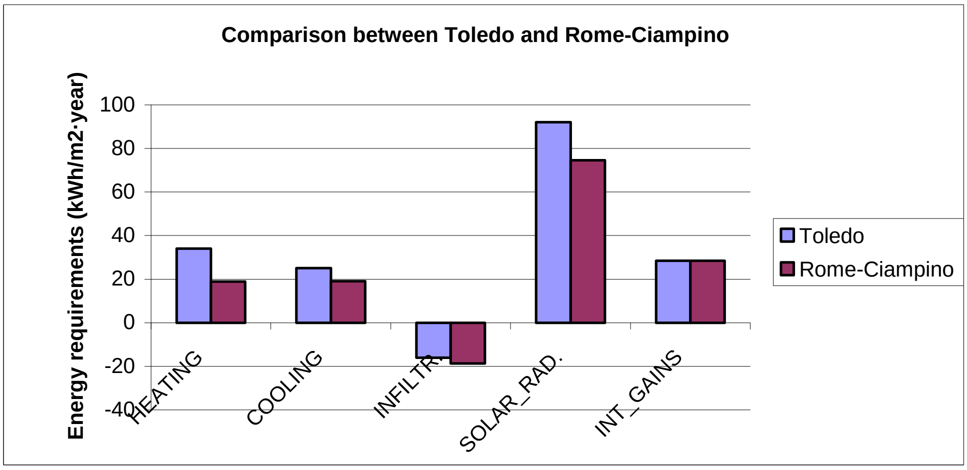


Figure 5-2.4 Energy requirements and gains obtained for the comparison between Toledo and Rome.

Energy requirement	Heating (kWh/m^{2}year)	Cooling (kWh/m^{2}year)	Total energy consumption (kWh/m^{2}year)
Toledo	34,0	25,1	59,2
Rome-Ciampino	18,8	19,0	37,9

Chart 5-2.5. Heating and cooling requirements for the comparison between Toledo and Rome.

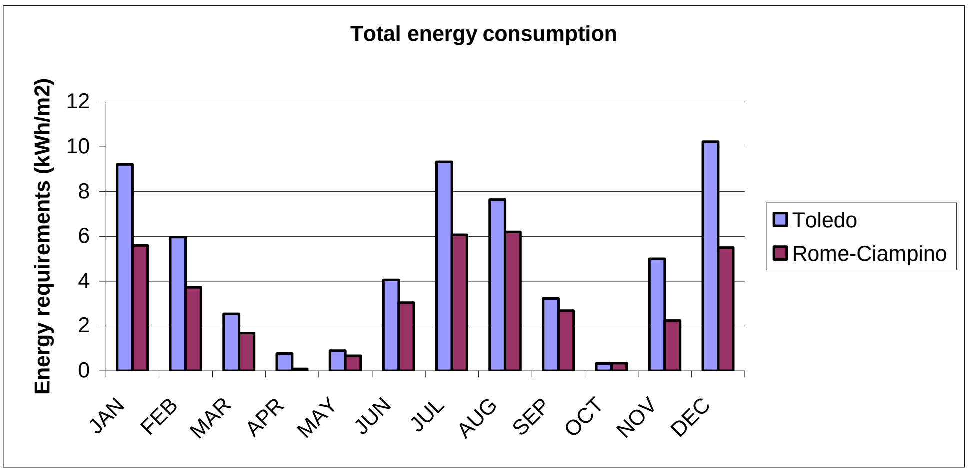


Figure 5-2.5.Total energy consumption obtained for the comparison between Toledo and Rome.

Madrid Vs. Trieste:

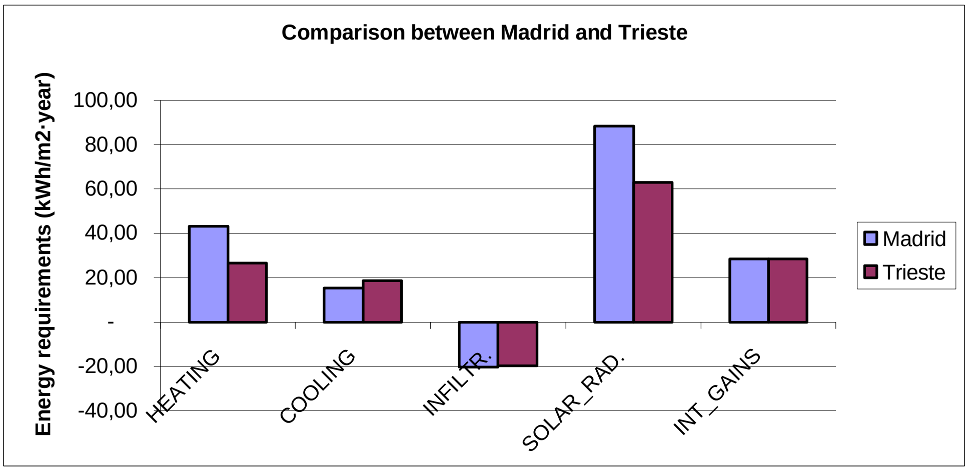


Figure 5-2.6 Energy requirements and gains obtained for the comparison between Madrid and Trieste.

Energy requirement	Heating ($kWh/m^2 year$)	Cooling ($kWh/m^2 year$)	Total energy consumption ($kWh/m^2 year$)
Madrid	43,20	15,27	58,47
Trieste	26,59	18,72	45,31

Chart 5-2.6. Heating and cooling requirements for the comparison between Madrid and Trieste.

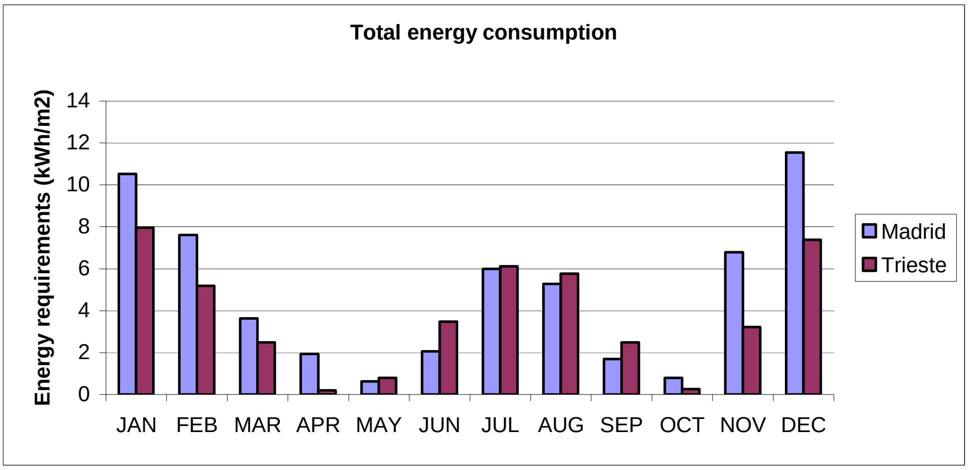


Figure 5-2.7.Total energy consumption obtained for the comparison between Madrid and Trieste.

Step 2:

<u>Almeria Vs. Palermo:</u>

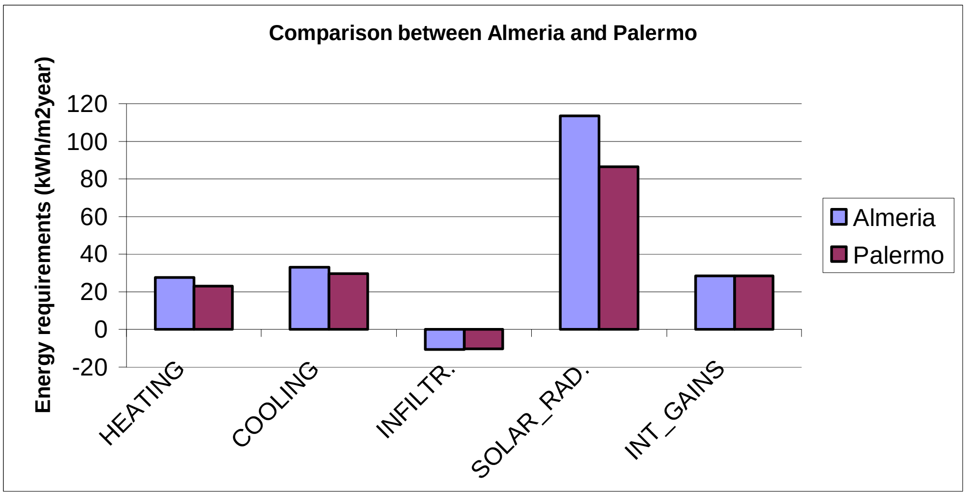


Figure 5-2.8 Energy requirements and gains obtained for the comparison between Almeria and Palermo with thermal bridges.

Energy requirement	Heating (kWh/m^2year)	Cooling (kWh/m^2year)	Total energy consumption (kWh/m^2year)
Almeria	27.56	33.03	60.58
Palermo	23.22	29.63	52.85

Chart 5-2.7. Heating and cooling requirements for the comparison between Almeria and Palermo with thermal bridges.

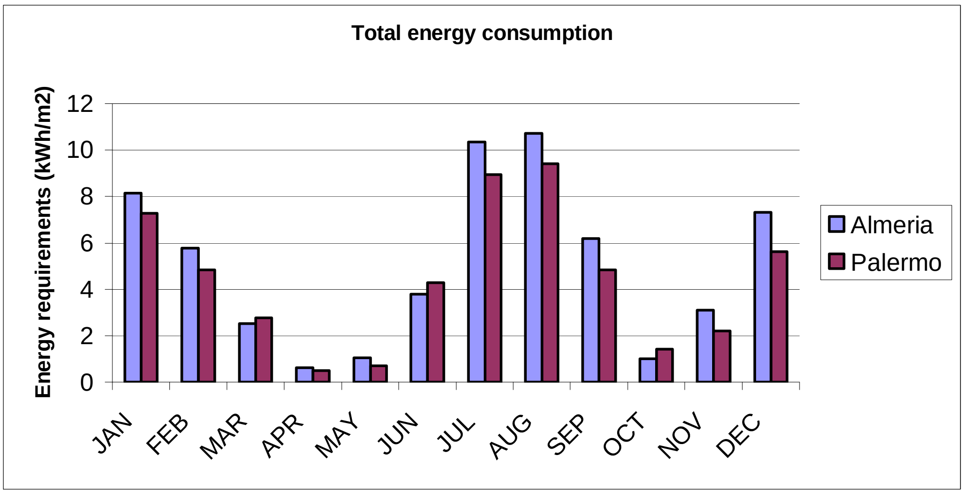


Figure 5-2.9 Total energy consumption obtained for the comparison between Almeria and Palermo with thermal bridges.

Toledo Vs. Rome-Ciampino:

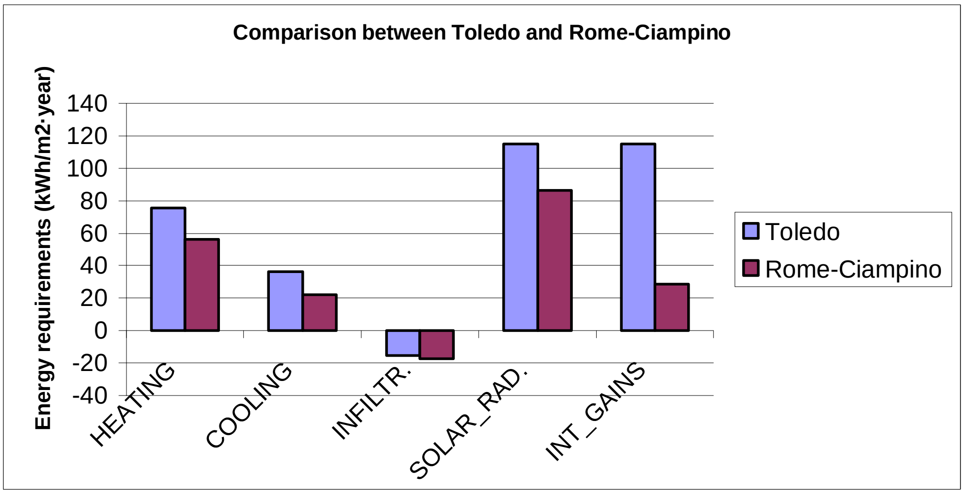


Figure 5-2.10 Energy requirements and gains obtained for the comparison between Toledo and Rome with thermal bridges.

Energy requirement	Heating ($kWh/m^2 year$)	Cooling ($kWh/m^2 year$)	Total energy consumption ($kWh/m^2 year$)
Toledo	75,49	36,25	111,74
Rome-Ciampino	56,1	22,0	78,18

Chart 5-2.8. Heating and cooling requirements for the comparison between Toledo and Rome with thermal bridges

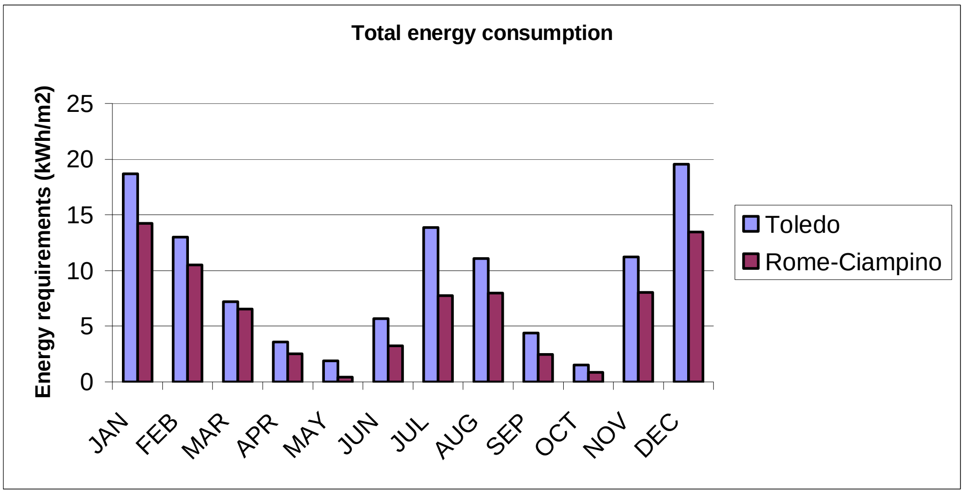


Figure 5-2.11 Total energy consumption obtained for the comparison between Toledo and Rome with thermal bridges.

Madrid Vs. Trieste:

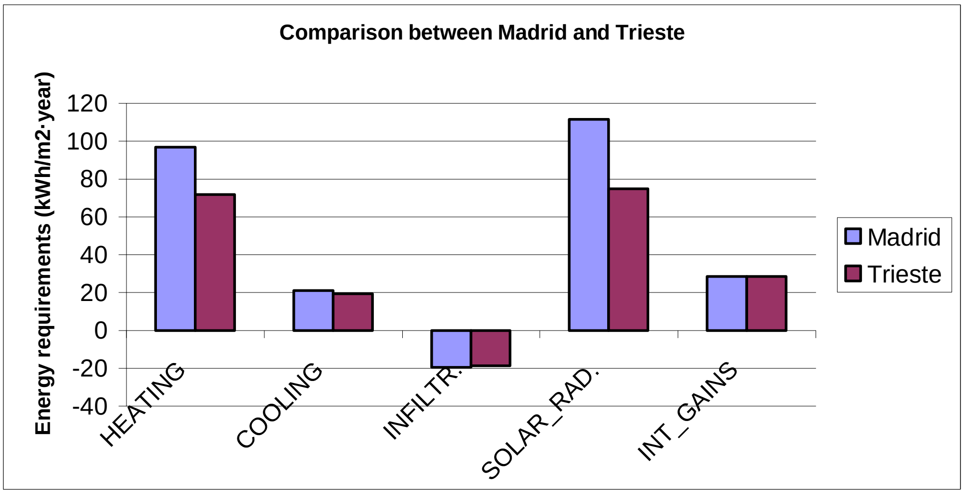


Figure 5-2.12 Energy requirements and gains obtained for the comparison between Madrid and Trieste with thermal bridges

Energy requirement	Heating (kWh/m^2year)	Cooling (kWh/m^2year)	Total energy consumption (kWh/m^2year)
Madrid	96,89	21,02	117,911
Trieste	71,95	19,54	91,486

Chart 5-2.9. Heating and cooling requirements for the comparison between Madrid and Trieste with thermal bridges

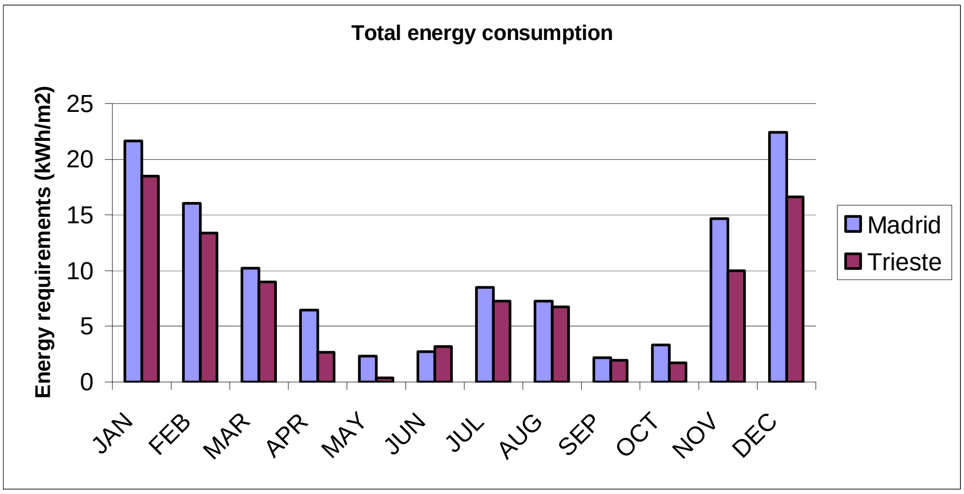


Figure 5-2.13 Total energy consumption obtained for the comparison between Madrid and Trieste with thermal bridges

6. CONCLUSIONS

As we have seen, this study has been focused on two main objectives. The first one was the comparison between the current software for the validation of energy performance in buildings, detailed in the “Rapporto sull’analisi di codici di calcolo per la valutazione enrgetica degli edifici” -which is explained in the chapter 3 of the present study-, with the results obtained with TRNSYS. The characteristics and boundary conditions of the building presented in the report of the chapter 3, were defined on TRNSYS at the most accurate manner possible. Although these characteristics were very close to the actual ones defined in the report, there are several slight differences that should be mentioned:

- The first one, is that the simulation on TRNSYS was carried out with TRNSYS own weather data (TMY2 files). This will the main reason of the possible discrepancies between the results, as we will see.
- The second one, is that TRNSYS does not allow entering user-defined inputs for the windows. The value for the glazing transmittance has been fit to the closest value included in TRNSYS library. This might be a reason for possible slight differences.

The second objective was to compare Italian and Spanish national regulations on energy performance of buildings. This has been done by selecting cities from both countries with similar weather. The results obtained during the simulation, will be used to tell which regulation is more restrictive.

This process has been divided into two different phases. The Phase 1 which details the first objective and the Phase 2 which details the second.

Phase 1:

The comparison between software has been done for three different cities, (Milan, Rome, and Palermo), in which we have tried to represent all the range of climatic zones existing in Italy. The results of this comparison are shown in the charts 5-1.2, 5-1.3, and 5-1.4 of chapter 5 (Results). The results have been compared with all the programs detailed in chapter 3, and especially, with MC4 Software, which is the program used at the laboratory of the “Università degli study di Perugia”. In theory, TRNSYS should give us the most accurate results, since TRNSYS is a transient system simulation program, which actually calculates the effects of thermal inertia, and not just evaluate them.

As we see, the simulation on TRNSYS, (step 1), shows a good approximation to the values obtained with the other programs, mainly, for cold zones such as Rome and Milan. In fact, these values are very close to the ones obtained with MC4 Software. The difference between the simulation on TRNSYS and MC4 for the location of Milan is a 1,37% and for the location of Rome is approximately a 10%. These differences might seem high, but if we focus on the other programs, the differences observed between them are greater. As an example, if we compare the values obtained for the location of Milan between the programs DOCET and MC4 the difference obtained is a 56%. Apart from some programs which show unusual high-values in the simulation, such as PHPP 2007it, CASA CLIMA, BEST CLASS, DOCET, the rest of the programs show a good fitting to the results obtained with TRNSYS for the cold regions. Graphically, we can see the differences on the figures 5-1.3 and 5-1.5 (Chapter 5).

On the other hand, for warm regions such as Palermo, the values obtained with TRNSYS are too low. In fact, the difference between MC4 Software and TRNSYS for the location of Palermo is a 72%, approximately. Graphically we can see these differences on the figure 5-1.7 (Chapter 5). This might happen because the simulation performed without thermal bridges is not real since it does not take into account the heat loss due to thermal bridges. So, TRNSYS calculates the sun's radiation heating the building and passing through the windows, and because of the building has no heat leakage through thermal bridges, this radiation is accumulated inside the building. This causes the unexpected low values for heating energy requirements.

This is why the second step of the simulation has been done, to take into account the heat loss caused by the thermal bridges. Thermal bridges are always present in constructions; windows and door frames, corners of the building, pillars... Are just a few examples. So, if a real simulation is wanted, thermal bridges must be included on it.

Now, focusing in the results obtained with thermal bridges, we observe that the results of the comparison are closer (charts 5-1.5, 5-1.6, and 5-1.7 of chapter 5). For cold locations such as Milan and Rome the differences obtained between MC4 Software and TRNSYS were 14% and 23%, respectively. And for warm locations such as Palermo the difference obtained was a 20%. The rest of the software analyzed show a good fit to TRNSYS except for the results obtained with programs CASA CLIMA and PHPP 2007it, which are higher. Figures 5-1.9, 5-1.11, and 5-1.13 show this behaviour.

Another way to justify the discrepancy between the results obtained in the step 1, is the climatic data used during the simulation. While all the software presented in the report of chapter 3, except from PHPP, read climatic data from the European regulation UNI 10349, TRNSYS and PHPP use climatic data from the data-base Meteonorm. In fact, TRNSYS and PHPP show the same behaviour. The results of the simulation performed with TRNSYS show a great gap between the heating energy requirements obtained for the location of Rome (11,8 $\frac{kWh}{m^2 year}$) and the energy requirements obtained for Palermo (1,48 $\frac{kWh}{m^2 year}$), as we see, there is a great difference between both of them. Now, if we observe the results obtained with the program PHPP, (for Rome 22 $\frac{kWh}{m^2 year}$ and for Palermo 3 $\frac{kWh}{m^2 year}$), there is also a great gap between both locations. In fact, the decreasing rate in both cases is very similar: For TRNSYS $\frac{11,8}{1,48} = 7,97$ and for PHPP $\frac{22}{3} = 7,33$. This could be a coincidence, or could be, plus the reasons explained above, the cause of the unexpected low values obtained during the simulation for Palermo.

Enclosed with the results of chapter 5, we detail several graphics (figures 5-1.4, 5-1.6 and 5-1.8 for the step 1, and figures 5-1.10, 5-1.12 and 5-1.14 for the step 2) in which the temperature variation throughout a whole year is shown. These graphics enable us to tell how cold is a certain location, or how much energy is required to heat or cool the building in that location. We observe that, the colder a certain location is, the longer is the horizontal line set at 20ºC, i.e., winter energy requirements are needed for longer in cold regions than in warm regions. We can illustrate this with a comparison between temperature variations in Milan (figure 5.4) and in Palermo (figure 5.8) as an example. On the other hand, we see how the horizontal line set at 26ºC becomes longer in warm locations for the same reason.

Phase 2

In this phase the main objective was to compare the different national regulations on energy performance of buildings in two Mediterranean countries like Italy and Spain. The aim of this section, was to analyse transpositions of the European directive on the energy performance of buildings in both countries. To do this, in the chapter of results (Chapter 5), there are detailed graphics and charts with heating and cooling energy requirements, heat loss due to infiltrations, external gains from sun's radiation and internal convective gains from people and equipment.

The first thing noticed from this comparison, is that the Italian regulation is more restrictive than the Spanish. For all the simulations done, in this second phase, winter energy requirements were higher for all the Spanish locations than the Italian. Also, cooling energy requirements were higher in Spain except for the comparison made between Madrid and Trieste in the step 1 (No thermal bridges. Figure 5-2.6 and chart 5-2.6). We can observe, how radiation is higher for all the simulations run for Spanish cities. This can be an explanation of why cooling requirements are usually higher in Spain. According to this reasoning, heating requirements should be lower thanks to the gains coming from radiation, but, strikingly, these requirements are higher, too. Therefore, we can conclude that Italian regulation is a higher energy-saver than the Spanish. In fact, if we focus on the maximum transmittances permitted by the regulations in both countries, we could, somehow, have advanced the results obtained, because the transmittances allowed by the Spanish law are higher than the Italians for all the locations studied.

During the second phase of the results, we have been able to see, other interesting facts. For instance, on the graphics that show the total energy consumption, (figures 5-2.3, 5-2.5 and 5-2.7 for the first step, and 5-2.9, 5-2.11 and 5-2.13 for the second step), we can see that the lowest energy-consumer months of year are April and May for almost all the locations. April and May are the months were almost no cooling or heating energy is required in Mediterranean Countries. On the other hand, the highest energy-consumer months of the year are December and January in winter and July and August in summer. Also, it can be noticed that, for seaside regions such as Palermo and Almeria, cooling energy requirements are higher than heating requirements. This is shown in the charts (5-2.4 and 5-2.7). So, apart from making efforts to reduce heating requirements, an effort focused on reducing cooling requirements should be made, as well.

The results obtained in the Phase 2, can be used to tell the existing gap between a perfectly insulated building, and a building with heating leakage through thermal bridges. These results show that this difference can represent from a 50% up to a 66% of the primary energy required for heating, depending on the climatic location analyzed, and from a 4% up to a 36% of the primary energy required for cooling. So, in theory, a perfectly-insulated building, i.e., a building with out thermal bridges could save up to a 66% of the energy used for heating and a 36% of the energy required for cooling.

To sum up, two main conclusions can be summarized from this study:

- The first one, is that TRNSYS is a valid software to simulate energy requirements and the thermal behaviour of a certain building. To do this, all the building's characteristics and boundary conditions have to be carefully defined. Although, there are several factors that should be taken into account: First, TRNSYS not always permits to user-define characteristics of some components of building's envelope, like the windows. Second, the main visual interface of TRNSYS does not allow introducing building's geometry by a drawing like some of the other programs with CAD visual interface mentioned do. So, is quite difficult to define the external geometry of the building with TRNBuild. Also, we have seen the influence of the weather data on the simulation. TRNSYS weather data-base does not include the European climatic data from regulation UNI 10349 to make an actual comparison between software. During this project, we have tried to import TRNSYS weather data to MC4 to tell the real differences between both programs but, without any interesting result. So, it would be an interesting project for the future to import the European weather data to TRNSYS. In the appendix, it is included some information that it has been considered useful. In fact, in the appendix there is included a reference that explains how to export TRNSYS weather data to other programs (TMY2 files).
- The second one, is that Italian transposition of the European Directive on energy performance of buildings, is more restrictive than the Spanish. Here we should mention that Italian regulation is supposed to change and become more restrictive in the year 2010, (all the simulations done in the second phase of the project, were done under the regulation of the year 2008). It has been explained the influence of thermal bridges on building's thermal behaviour. Reducing heating leakages through thermal bridges can represent an efficient and economic way to save energy and cutting greenhouse gases emissions. So, could be a way to contribute to the global solution to the energy problem existing nowadays.

7. APPENDIX.

7.1 Thermal zones classification of province capitals in Spain.

Capital de provincia	Capital	Altura de referencia (m)
Albacete	D3	677
Alicante	B4	7
Almería	A4	0
Ávila	E1	1054
Badajoz	C4	168
Barcelona	C2	1
Bilbao	C1	214
Burgos	E1	861
Cáceres	C4	385
Cádiz	A3	0
Castellón de la Plana	B3	18
Ceuta	B3	0
Ciudad real	D3	630
Córdoba	B4	113
Coruña (a)	C1	0
Cuenca	D2	975
Donostia-San Sebastián	C1	5
Girona	C2	143
Granada	C3	754
Guadalajara	D3	708
Huelva	B4	50
Huesca	D2	432
Jaén	C4	436
León	E1	346
Lleida	D3	131
Logroño	D2	379
Lugo	D1	412
Madrid	D3	589
Málaga	A3	0
Melilla	A3	130
Murcia	B3	25
Ourense	C2	327
Oviedo	C1	214
Palencia	D1	722
Palma de Mallorca	B3	1
Palmas de Gran Canaria (las)	A3	114
Pamplona	D1	456
Pontevedra	C1	77
Salamanca	D2	770
Santa Cruz de Tenerife	A3	0
Santander	C1	1
Segovia	D2	1013
Sevilla	B4	9
Soria	E1	984
Tarragona	B3	1
Teruel	D2	995
Toledo	C4	445
Valencia	B3	8
Valladolid	D2	704
Vitoria-Gasteiz	D1	512
Zamora	D2	617
Zaragoza	D3	207

7.2 Maximum transmittances permitted by the Spanish regulation depending on the thermal zone:.

Thermal zone A3:

ZONA CLIMÁTICA A3

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,94 W/m² K**
Transmitancia límite de suelos	**U_{Slim}: 0,53 W/m² K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,50 W/m² K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,29**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m²K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	5,7	5,7	5,7	5,7	-	-	-	-	-	-
de 11 a 20	4,7 (5,6)	5,7	5,7	5,7	-	-	-	-	-	-
de 21 a 30	4,1 (4,6)	5,5 (5,7)	5,7	5,7	-	-	-	0,60	-	-
de 31 a 40	3,8 (4,1)	5,2 (5,5)	5,7	5,7	-	-	-	0,48	-	0,51
de 41 a 50	3,5 (3,8)	5,0 (5,2)	5,7	5,7	0,57	-	0,60	0,41	0,57	0,44
de 51 a 60	3,4 (3,6)	4,8 (4,9)	5,7	5,7	0,50	-	0,54	0,36	0,51	0,39

Thermal zone A4

ZONA CLIMÁTICA A4

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,94 W/m²K**
Transmitancia límite de suelos	**U_{Slim}: 0,53 W/m²K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,50 W/m²K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,29**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m²K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	5,7	5,7	5,7	5,7	-	-	-	-	-	-
de 11 a 20	4,7 (5,6)	5,7	5,7	5,7	-	-	-	-	-	-
de 21 a 30	4,1 (4,6)	5,5 (5,7)	5,7	5,7	-	-	-	0,56	-	0,57
de 31 a 40	3,8 (4,1)	5,2 (5,5)	5,7	5,7	0,57	-	0,58	0,43	0,59	0,44
de 41 a 50	3,5 (3,8)	5,0 (5,2)	5,7	5,7	0,47	-	0,48	0,35	0,49	0,37
de 51 a 60	3,4 (3,6)	4,8 (4,9)	5,7	5,7	0,40	0,55	0,42	0,30	0,42	0,32

Thermal zone B3:

ZONA CLIMÁTICA B3

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,82 W/m²K**
Transmitancia límite de suelos	**U_{Slim}: 0,52 W/m²K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,45 W/m²K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,30**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m²K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	5,4 (5,7)	5,7	5,7	5,7	-	-	-	-	-	-
de 11 a 20	3,8 (4,7)	4,9 (5,7)	5,7	5,7	-	-	-	-	-	-
de 21 a 30	3,3 (3,8)	4,3 (4,7)	5,7	5,7	-	-	-	0,57	-	-
de 31 a 40	3,0 (3,3)	4,0 (4,2)	5,6 (5,7)	5,6 (5,7)	-	-	-	0,45	-	0,50
de 41 a 50	2,8 (3,0)	3,7 (3,9)	5,4 (5,5)	5,4 (5,5)	0,53	-	0,59	0,38	0,57	0,43
de 51 a 60	2,7 (2,8)	3,6 (3,7)	5,2 (5,3)	5,2 (5,3)	0,46	-	0,52	0,33	0,51	0,38

Thermal zone B4:

ZONA CLIMÁTICA B4

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,82 W/m²K**
Transmitancia límite de suelos	**U_{Slim}: 0,52 W/m²K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,45 W/m²K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,28**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m²K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	5,4 (5,7)	5,7	5,7	5,7	-	-	-	-	-	-
de 11 a 20	3,8 (4,7)	4,9 (5,7)	5,7	5,7	-	-	-	-	-	-
de 21 a 30	3,3 (3,8)	4,3 (4,7)	5,7	5,7	-	-	-	0,55	-	0,57
de 31 a 40	3,0 (3,3)	4,0 (4,2)	5,6 (5,7)	5,6 (5,7)	0,55	-	0,58	0,42	0,59	0,44
de 41 a 50	2,8 (3,0)	3,7 (3,9)	5,4 (5,5)	5,4 (5,5)	0,45	-	0,48	0,34	0,49	0,36
de 51 a 60	2,7 (2,8)	3,6 (3,7)	5,2 (5,3)	5,2 (5,3)	0,39	0,55	0,41	0,29	0,42	0,31

Thermal zone C1:

ZONA CLIMÁTICA C1

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,73 W/m²K**
Transmitancia límite de suelos	**U_{Slim}: 0,50 W/m²K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,41 W/m²K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,37**

% de superficie de huecos	Transmitancia límite de huecos[1] U_{Hlim} W/m²K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	4,4	4,4	4,4	4,4	-	-	-	-	-	-
de 11 a 20	3,4 (4,2)	3,9 (4,4)	4,4	4,4	-	-	-	-	-	-
de 21 a 30	2,9 (3,3)	3,3 (3,8)	4,3 (4,4)	4,3 (4,4)	-	-	-	-	-	-
de 31 a 40	2,6 (2,9)	3,0 (3,3)	3,9 (4,1)	3,9 (4,1)	-	-	-	0,56	-	0,60
de 41 a 50	2,4 (2,6)	2,8 (3,0)	3,6 (3,8)	3,6 (3,8)	-	-	-	0,47	-	0,52
de 51 a 60	2,2 (2,4)	2,7 (2,8)	3,5 (3,6)	3,5 (3,6)	-	-	-	0,42	-	0,46

Thermal zone C2:

ZONA CLIMÁTICA C2

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,73 W/m^{2}K**
Transmitancia límite de suelos	**U_{Slim}: 0,50 W/m^{2}K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,41 W/m^{2}K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,32**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	4,4	4,4	4,4	4,4	-	-	-	-	-	-
de 11 a 20	3,4 (4,2)	3,9 (4,4)	4,4	4,4	-	-	-	-	-	-
de 21 a 30	2,9 (3,3)	3,3 (3,8)	4,3 (4,4)	4,3 (4,4)	-	-	-	0,60	-	-
de 31 a 40	2,6 (2,9)	3,0 (3,3)	3,9 (4,1)	3,9 (4,1)	-	-	-	0,47	-	0,51
de 41 a 50	2,4 (2,6)	2,8 (3,0)	3,6 (3,8)	3,6 (3,8)	0,59	-	-	0,40	0,58	0,43
de 51 a 60	2,2 (2,4)	2,7 (2,8)	3,5 (3,6)	3,5 (3,6)	0,51	-	0,55	0,35	0,52	0,38

Thermal zone C3:

ZONA CLIMÁTICA C3

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,73 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,50 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,41 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,28**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	4,4	4,4	4,4	4,4	-	-	-	-	-	-
de 11 a 20	3,4 (4,2)	3,9 (4,4)	4,4	4,4	-	-	-	-	-	-
de 21 a 30	2,9 (3,3)	3,3 (3,8)	4,3 (4,4)	4,3 (4,4)	-	-	-	0,55	-	0,59
de 31 a 40	2,6 (2,9)	3,0 (3,3)	3,9 (4,1)	3,9 (4,1)	-	-	-	0,43	-	0,46
de 41 a 50	2,4 (2,6)	2,8 (3,0)	3,6 (3,8)	3,6 (3,8)	0,51	-	0,54	0,35	0,52	0,39
de 51 a 60	2,2 (2,4)	2,7 (2,8)	3,5 (3,6)	3,5 (3,6)	0,43	-	0,47	0,31	0,46	0,34

Thermal C4:

ZONA CLIMÁTICA C4

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,73 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,50 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,41 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,27**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	4,4	4,4	4,4	4,4	-	-	-	-	-	-
de 11 a 20	3,4 (4,2)	3,9 (4,4)	4,4	4,4	-	-	-	-	-	-
de 21 a 30	2,9 (3,3)	3,3 (3,8)	4,3 (4,4)	4,3 (4,4)	-	-	-	0,54	-	0,56
de 31 a 40	2,6 (2,9)	3,0 (3,3)	3,9 (4,1)	3,9 (4,1)	0,54	-	0,56	0,41	0,57	0,43
de 41 a 50	2,4 (2,6)	2,8 (3,0)	3,6 (3,8)	3,6 (3,8)	0,47	-	0,46	0,34	0,47	0,35
de 51 a 60	2,2 (2,4)	2,7 (2,8)	3,5 (3,6)	3,5 (3,6)	0,38	0,53	0,39	0,29	0,40	0,30

Thermal zone D1:

ZONA CLIMÁTICA D1

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,66 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,49 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,38 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,36**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	3,5	3,5	3,5	3,5	-	-	-	-	-	-
de 11 a 20	3,0 (3,5)	3,5	3,5	3,5	-	-	-	-	-	-
de 21 a 30	2,5 (2,9)	2,9 (3,3)	3,5	3,5	-	-	-	-	-	-
de 31 a 40	2,2 (2,5)	2,6 (2,9)	3,4 (3,5)	3,4 (3,5)	-	-	-	0,54	-	0,58
de 41 a 50	2,1 (2,2)	2,5 (2,6)	3,2 (3,4)	3,2 (3,4)	-	-	-	0,45	-	0,49
de 51 a 60	1,9 (2,1)	2,3 (2,4)	3,0 (3,1)	3,0 (3,1)	-	-	-	0,40	0,57	0,44

Thermal zone D2:

ZONA CLIMÁTICA D2

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,66 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,49 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,38 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,31**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	3,5	3,5	3,5	3,5	-	-	-	-	-	-
de 11 a 20	3,0 (3,5)	3,5	3,5	3,5	-	-	-	-	-	-
de 21 a 30	2,5 (2,9)	2,9 (3,3)	3,5	3,5	-	-	-	0,58	-	0,61
de 31 a 40	2,2 (2,5)	2,6 (2,9)	3,4 (3,5)	3,4 (3,5)	-	-	-	0,46	-	0,49
de 41 a 50	2,1 (2,2)	2,5 (2,6)	3,2 (3,4)	3,2 (3,4)	-	-	0,61	0,38	0,54	0,41
de 51 a 60	1,9 (2,1)	2,3 (2,4)	3,0 (3,1)	3,0 (3,1)	0,49	-	0,53	0,33	0,48	0,36

Thermal zone D3:

ZONA CLIMÁTICA D3

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,66 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,49 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,38 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,28**

% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	3,5	3,5	3,5	3,5	-	-	-	-	-	-
de 11 a 20	3,0 (3,5)	3,5	3,5	3,5	-	-	-	-	-	-
de 21 a 30	2,5 (2,9)	2,9 (3,3)	3,5	3,5	-	-	-	0,54	-	0,57
de 31 a 40	2,2 (2,5)	2,6 (2,9)	3,4 (3,5)	3,4 (3,5)	-	-	-	0,42	0,58	0,45
de 41 a 50	2,1 (2,2)	2,5 (2,6)	3,2 (3,4)	3,2 (3,4)	0,50	-	0,53	0,35	0,49	0,37
de 51 a 60	1,9 (2,1)	2,3 (2,4)	3,0 (3,1)	3,0 (3,1)	0,42	0,61	0,46	0,30	0,43	0,32

Thermal zone E1:

ZONA CLIMÁTICA E1

Transmitancia límite de muros de fachada y cerramientos en contacto con el terreno	**U_{Mlim}: 0,57 W/m^2 K**
Transmitancia límite de suelos	**U_{Slim}: 0,48 W/m^2 K**
Transmitancia límite de cubiertas	**U_{Clim}: 0,35 W/m^2 K**
Factor solar modificado límite de lucernarios	**F_{Llim}: 0,36**

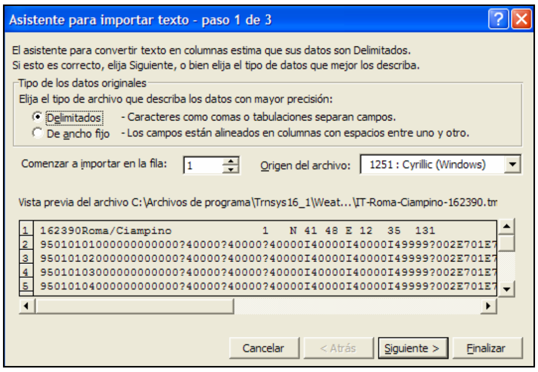
% de superficie de huecos	Transmitancia límite de huecos(1) U_{Hlim} W/m^{2}K				Factor solar modificado límite de huecos F_{Hlim}					
					Carga interna baja			Carga interna alta		
	N	E/O	S	SE/SO	E/O	S	SE/SO	E/O	S	SE/SO
de 0 a 10	3,1	3,1	3,1	3,1	-	-	-	-	-	-
de 11 a 20	3,1	3,1	3,1	3,1	-	-	-	-	-	-
de 21 a 30	2,6 (2,9)	3,0 (3,1)	3,1	3,1	-	-	-	-	-	-
de 31 a 40	2,2 (2,4)	2,7 (2,8)	3,1	3,1	-	-	-	0,54	-	0,56
de 41 a 50	2,0 (2,2)	2,4 (2,6)	3,1	3,1	-	-	-	0,45	0,60	0,49
de 51 a 60	1,9 (2,0)	2,3 (2,4)	3,0 (3,1)	3,0 (3,1)	-	-	-	0,40	0,54	0,43

7.3 Useful information:

In this section, we detail some information about processing weather data from TRNSYS, which might be useful for future investigations. Here, we will explain the process that should be followed in order to import TMY2 files from TRNSYS database to other programs.

The process is quite simple, though it may take a little bit.

1. Open a TMY2 file with MS EXCEL. Select *All Files* in the Files of Type dropdown menu of the Open window and select your TMY2 file [example.tm2]. The Text Import Wizard window will appear. Select *fixed width* as the original data type and click *next*.



2. Next, you are asked to identify the boundaries of the columns separating each piece of data. In the following web site, we will find out were to place the boundaries for each physical variable: http://rredc.nrel.gov/solar/pubs/tmy2/tab3-2.html. Use the scale at the top of the data as a guide. This scale corresponds to the variable of the TMY2.

3. Lastly, click Finish. The tmy2 data set will be imported to MS EXCEL.

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Chapter 2: Regulations analyzed:

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Capter 4. TRNSYS description.

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